APPLIED GEOGRAPHY

AN INTRODUCTION
TO
APPLIED GEOGRAPHY

BY

ALEXANDER STEVENS, M.A., B.Sc.
Lecturer in Geography, University of Glasgow

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PREFACE

This book has been written to provide a course of study in Geography for those who propose to enter professions in which a knowledge of practical geography is essential. The navigator, land surveyor, mining engineer, and prospector must all possess a working knowledge of the contents of this book if they are to follow intelligently the computations they are daily called upon to make. These calculations necessarily involve a certain amount of mathematics, which has been kept as simple as possible.

The writer acknowledges gratefully the valuable services of Mrs. A. Walker Buchanan, who has been so kind as to read the proofs.

A. STEVENS.

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APPLIED GEOGRAPHY

CHAPTER I

THE FIGURE OF THE EARTH

Since the time of Aristotle thinking men have known that the form of the earth is globular. Assuming this, modern workers with modern refined methods of measurement have been able to show that the earth is not quite a true sphere, nor yet any regular geometrical figure. They have found it necessary to rest content with the nearest approximate regular figure. For our purpose it will be sufficiently close if we take it that the earth is a sphere, and a study of the elements of the geometry of the sphere will enable us to form more precise ideas in the subject of geography, and to appreciate how more exact knowledge of the Figure of the Earth is obtained.

Assuming that the earth is spherical in form, the only exact representation of it is a globe (see Chapter III). In order to follow what we have to say, it is necessary to have the use of a globe, and to accustom oneself to picturing the globe or parts of it. It is not convenient or easy to cut up our globes, however, and it will be useful to consider an orange or a ball as representing the earth.

If we take an orange and cut it *straight across*, we shall have two pieces with the cut surfaces perfectly flat, and circular in outline. Such flat surfaces are referred to as "plane sections" of the orange. We can imagine a plane passing through the globe and giving such circular plane sections. All plane sections of the sphere are circular. The number of possible plane sections of a sphere is indefinite.

Plane Sections of the Sphere.—Take some pieces of stiff card and cut out of them circles of different sizes. One of these should be of the same diameter as the globe, one may be larger, but there should be one or two of less diameter. One of these can be set on the globe to sit on it like the brim of a hat, resting on the edge of the circular hole. The card fits the sphere exactly along the circle. If the hole is not circular, its edge will not fit close to the sphere. The surface of the card can be pictured to extend through the globe and to intersect it in a circle of the diameter of the hole. If a pencil be passed round the edge of the hole, the circle will be drawn on the sphere. If the circular hole is of diameter greater than that of the sphere, the card will slip over the globe. If the card with the hole of the same diameter as the sphere be used, it will just fit round the middle of the globe like a girdle. It can be fitted in many positions, but it will always mark off two hemispheres. Thus the greatest circle which can be drawn on the sphere, or the greatest plane section of the sphere, is of the same diameter as the sphere, and the plane of such a section passes through the centre of the sphere. Any number of such sections of the sphere can be made, and they are called **great circles.**

All other circles which can be drawn on the sphere are of smaller diameter. They are called **small circles,**

and they may be of any diameter smaller than that of the sphere. The number of small circles which can be drawn on the sphere is unlimited, but the planes of none of them pass through the centre of the sphere (see fig. 1).

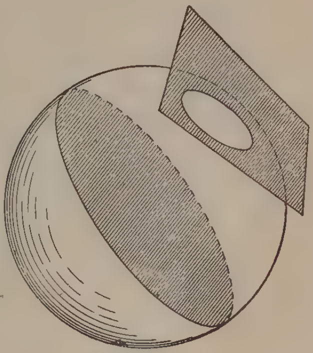


Fig. 1

A plane can be made to pass through any three points in space. It is easy to show this experimentally. Stick three wires of any length, the same or different, into a piece of wood so that they stand up vertically. The free ends of these wires (A, B, C) represent three points in space. A piece of card, representing a plane, can be set firmly on these three points. If a fourth wire is added, it is only by accident that the plane will rest on the ends of all four (fig. 2). A three-legged stool is always steady on its legs, even if by wear they have become of different lengths, or if the stool is set on an uneven floor. It is very different in the case of a four-legged

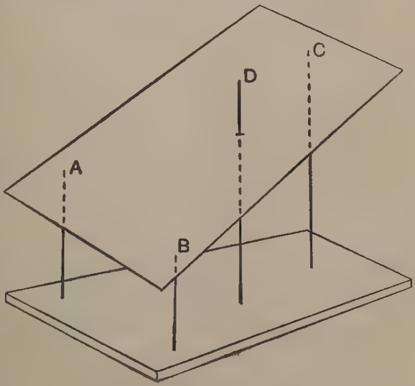


Fig. 2

table with legs of uneven length or set on an uneven floor.

Through three points on the surface of the globe a plane may be passed, or, in other words, a circle may be drawn through any three points on the surface of the globe. But a great circle can generally only be drawn through two points on the surface of the globe, because the centre of the sphere, through which the planes of all great circles must pass, provides the third point. Clearly, however, if a great circle passes through one point on the globe, it also passes through its antipodes. But, generally, through any two points on the surface of the globe only one great, but any number of small circles, may be drawn.

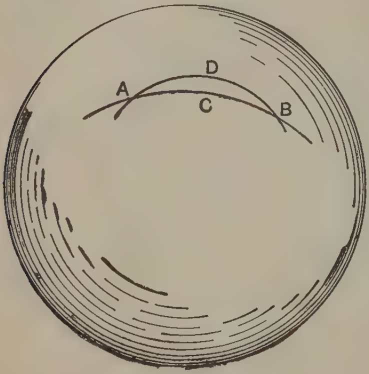


Fig. 3

Great Circles.—The great circle on the sphere is pretty much the same thing as the straight line in relation to the plane. On a plane the shortest distance between two points is along the straight line joining them. On the surface of the sphere the shortest distance between two points is the shorter arc of the great circle which passes through them (fig. 3). In fig. 3 the points A, B are joined by the arc of a great circle ACB, and by ADB, the arc of a small circle. Obviously, the longer way from A to B is by the arc of greater curvature, that is, by the small circle.

The earth is such a large sphere that the shortest distance between two points a mile apart seems to be a straight line. We see, however, that it is really an arc of a great circle, but the "up and down bend" of it is so slight that it is not noticed. If the two points were 10 miles apart on quite flat ground, or on opposite shores of a large lake or bay, they would be invisible from each other because of the curve of the earth's surface. In this case it becomes more obvious that the distance would be measured along a curved line. Fig. 4 makes it clear. A

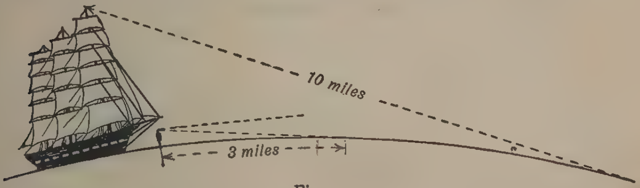


Fig. 4

man of ordinary height can see a point on flat ground at a distance of about 3 miles. If he is on a tower or at a mast-head, or in some other way at a greater height above the earth, his limit of vision is extended. His horizon is the circle that limits his vision. Clearly it is a small circle of the earth.

Meridians.—Certain circles on the terrestrial sphere are of particular importance. They enable us to define the position of any place on the surface of the earth, and they are themselves defined by their relation to the naturally fixed points on the earth. These points are the poles, the extremities of the polar diameter of the earth, which is also the axis about which the earth spins in its daily rotation. It is this rotation which fixes the position of the poles and enables us to determine them. They are the

only points on the surface of the earth which are fixed by nature.

The poles being the antipodes of each other, a great circle can be passed through both of them and through any other point on the surface of the earth. Such a great circle is called a meridian, or *the* meridian of the point other than the poles through which it is passed. The number of meridians is unlimited. Each point on the surface of the earth has its meridian, but the same meridian is the meridian of an unlimited number of places. The directions of north and south at any place lie along the meridian of the place.

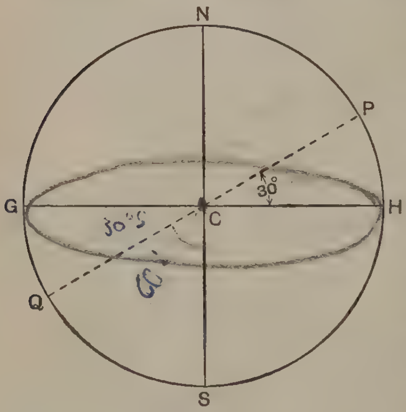


Fig. 5

Latitude. — All the meridians are bisected by the equator, which is the great circle whose plane is at right angles to the axis of the earth. The position of a place on its meridian is defined by reference to the point in which the equator crosses the meridian, or to the pole. In fig. 5 let the circle NPS be the meridian of P, passing through N, S, the north and south poles. C is the centre of the meridian (and of the earth). The equator cuts the meridian in G, H, and so the diameter GH is at right angles to NS. The angle PCH is the *angular distance* of P from H, or from the equator, and is called the latitude of P.

The angular distance of P from the north pole, N, the angle PCN, is the co-latitude of P. The co-latitude is thus the complement of the latitude. By means of the latitude (or the co-latitude) we are able to specify the position of a point on its meridian.

It is usual to think of the meridian of P as the semicircle NPS only, the other semicircle being the meridian of the antipodes of P. Even so, it is necessary to indicate whether the point P is in the quadrant NCH or in SCH, that is, whether it is north or south of the equator. If P lies north of the equator, it is in north latitude; thus, since the angle PCH in fig. 5 is 30 degrees, we say for short that P is in lat. 30° N. The position of Q is lat. 30° S.

Size and Shape of the Meridians.—The diameter of the earth, regarded as a sphere, may be taken as about 7920 miles. The circumference of the complete circle of the meridian is, therefore, some 24,880 miles, and the length of a quadrant is 6220 miles. Ninety degrees of latitude correspond at the surface of the earth to 6220 miles, and a single degree of latitude to just over 69 miles.

These "miles" are statute or "English" miles, each containing 1760 yd. But it is customary to divide the degrees into 60 equal parts called *minutes*, and the length of the meridian corresponding to 1 minute (1′) of latitude is called the geographical, nautical, or sea mile.[1] There are 90 times 60 minutes in a quadrant, and the student should verify the fact that there are 6080 ft. in a sea mile, which is to an ordinary or statute mile in the ratio of 38:33.

[1] The word "knot" does not mean the same as "sea mile". It is the unit of speed employed at sea, and refers to the rate at which knots made on a log-line ran out in the old-fashioned method of taking the speed of a vessel. It is quite wrong to say "ten knots an hour". The last two words should be omitted.

Measurements of the length of meridian at the surface of the earth corresponding to one degree of latitude have been made at different parts of different meridians, and it is found that it is not uniform. It varies from meridian to meridian in the same latitude, and it varies with the latitude. In general, it increases the higher the latitude, or the nearer to the pole the measurement is made. The average lengths, so far as known, are given in Table I.

TABLE I

At Latitude (N. or S.).	Length of 1 degree of Latitude in Statute Miles.
0 degrees	68·72
10 ,,	72
20 ,,	78
30 ,,	88
40 ,,	99
50 ,,	69·11
60 ,,	23
65 ,,	28
70 ,,	32
80 ,,	39
90 ,,	41

From these figures it is clear that the meridian is not a perfect circle, and the earth is not a perfect sphere. Also, the length of a minute of latitude is variable, and the nautical mile is the *mean* length of meridian corresponding to one minute of latitude.

In any circle, a given angle at the centre subtends a larger arc of the circumference than is subtended by an angle of the same size at the centre of a circle of smaller radius (see fig. 6). The curvature, or *rate of bend* of the circumference is greater in a

circle of small than in a circle of large radius. Since the meridian is not perfectly circular, we might think of it as composite—made up of arcs of circles of different radius. From what has been said, it follows that these arcs will be of greater radius and less curvature towards the poles than towards the equator. It is not possible to make a clear diagram to exact scale in a page the size of this, but fig. 7 shows a meridian made up of the arcs of two circles of different radius,

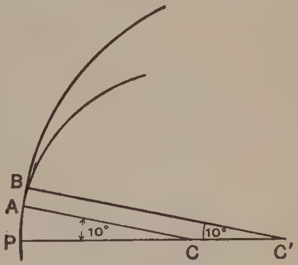


Fig. 6

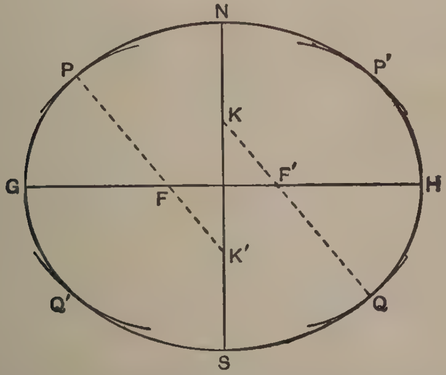


Fig. 7.—The meridian regarded as made up of polar arcs, PP′, QQ′, centres K′, K, radii K′P = K′N = KQ = KS, and equatorial arcs PQ′, P′Q, centres F, F′, radii FP = FG = F′Q = F′H. The prolongations of the arcs are shown as fine lines. Actually the meridian must be looked on as made up of many circular arcs, the radius of the arc at any point being the *radius of curvature* for that point.

and indicates the polar flattening of the meridian and of the earth.

Convergence of the Meridians.—Since the meridians all pass through the poles, any two meridians (e.g. BN, CN, fig. 8) approach more and more closely together as they near the pole. At any point A on the surface of the earth, the north direction is along the meridian AN. At the point A this is the same direction as along the tangent to the meridian at A. The direction of north at another point K on the same meridian is not the same as it is at A, because of the curvature of the meridian, but the tangents to the meridian at A and K lie in the plane of the meridian. At a point B on another meridian, the direction of north is along the meridian BN, or along the tangent to the meridian at that point, and it is not parallel to the direction of north at A or K. At the equator, however, the tangents to all the meridians are parallel; they are in the same direction. Considering any two meridians on the globe, we see that the directions of north (or south) are the same at the equator on the two meridians, but that as we move towards the poles the directions on different meridians in any given latitude become inclined to each other more and more, until at the poles the angle between them is the angle between the planes of the meridians. This is a very important property. It is called the

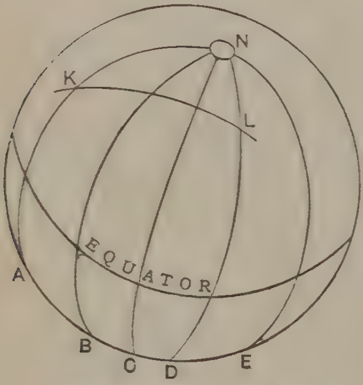


Fig. 8.—KL is a great circle

Convergence of the Meridians, and the student should follow it out very carefully on his globe until he grasps it thoroughly.

Consider any great circle drawn on the globe. Clearly, it does not cross all the meridians at the same angle (see fig. 8). In other words, its direction is continually changing throughout its course. Again, let K, L be two points on this great circle. The direction from K to L is the angle between the meridian at K and the arc KL. The direction *from* L *to* K is the angle between the meridian at L and the same arc, and, clearly, these two angles are not the same, neither are they supplementary. Hence the direction from one point to another is not the same as the direction from the second point to the first, although the directions we usually consider are between points so close that the difference is inappreciable. Thus, if the points are Liverpool and Manchester, the directions are L.–M. 80° 20′, M.–L. 261° 00′; but if the points are Liverpool and New York, they are L.–N.Y. 285° 15′, N.Y.–L. 49° 45′ (fig. 8). This is a very important consequence of the convergence of the meridians, and the student will do well to draw great circles on his globe by means of the piece of card with the circular hole of the same diameter as the globe (see p. 2), in order to study it thoroughly in practice.

Longitude. — Any meridian can be specified by indicating the point in which it crosses the equator; but for this purpose there is nothing to provide a natural starting-point, as the poles provide one for reckoning latitude. Hence we must arbitrarily choose a *prime* or *initial meridian* from which to count. Most civilized countries have a great observatory, and the meridian of that observatory was adopted as

initial in each country; but the obvious convenience of having everyone reckon from the same starting-point led to an international convention that all should employ as prime meridian the meridian of the observatory of Greenwich, and this convention is very generally obeyed. The angle at the centre of the earth, subtended by the arc of the equator, between the points where a given meridian and the prime meridian (that of Greenwich) cut the equator is called the **longitude** of that meridian (see fig. 9). It is the angle between the planes of the two meridians, and also the angle between the tangents to the meridians at the poles.

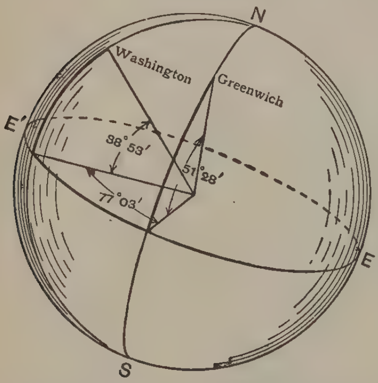


Fig. 9.—Latitude and Longitude: Greenwich, Lat. 51° 28′ N., Long. 00° 00′; Washington, Lat. 38° 53′ N., Long. 77° 03′ W.

Longitude is reckoned east or west from the meridian of Greenwich, and longitudes therefore run up to 180° east and west. The same meridian is in longitude 180° E. and 180° W.

By means of latitude and longitude we can now state exactly where on the surface of the earth a place is. For instance, the latitude and longitude, or, as they are called, the geographical co-ordinates of Washington, are lat. 38° 53′ N., long. 77° 03′ W. Choose on the globe the meridian which is 77° 03′ west of the meridian of Greenwich, and lay off 38° 53′ northward from the equator along it. The point reached is the position of Washington (see fig. 9).

Small Circles — Parallels.—The important small circles on the earth, those usually represented on globes and maps, are sections by planes parallel to the equator, and so at right angles to the axis or polar diameter of the earth. These circles are **parallels, or circles, of latitude**, and latitude is the same for all points of the same parallel. The equator is the largest parallel, all others being smaller the nearer they are to the pole, and the pole may be looked on as the smallest parallel, a point, or circle of zero radius.

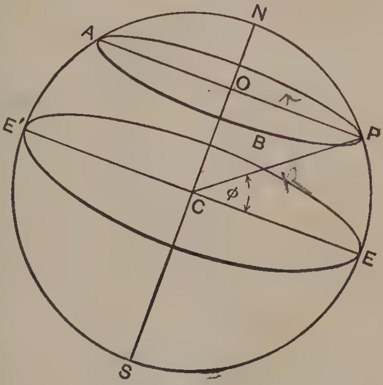


Fig. 10

It is important to be able to calculate the radius, and therefore the length of any parallel, and fortunately this is easy to do. In fig. 10 let ABP be the parallel of latitude ϕ. This parallel is a section of the surface of the earth by a plane at right angles to the axis of the earth, NS. Its centre therefore lies at O, the point of intersection of the plane of the parallel and the axis of the earth, and its radius is OP, length r. If the length of CP, the radius of the earth,[1] be R, then, from the figure,

$$OP/CP = \sin OCP = \cos ECP,$$

since the two angles are complementary.

[1] Or the radius of curvature of the meridian at P, if the earth is not regarded as spherical.

But these two angles are respectively the co-latitude ψ and latitude ϕ of P, that is, of the parallel. Hence

$$r = R \sin \psi = R \cos \phi.$$

Example.—

For the parallel of 60° N. (or S.), $\phi = 60°$, $\cos \phi = 0 \cdot 5$. Hence $r = \frac{1}{2}R$, or the radius of the parallel is half the radius of the earth.

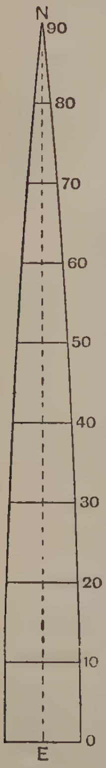


Fig. 11

Consider two meridians 1 degree of longitude apart, or, as it is usually put, of 1 degree difference of longitude. The distance between them along the equator is roughly 69 statute miles. From the example above, it follows that the distance between them where they cross the parallel of 60° N. is only half this, or rather over $34\frac{1}{2}$ miles. The student should verify this by calculating the length of the parallel of 60 degrees, and dividing the result by 360, since there are 360 degrees in the circle. The globe shows how the degrees of longitude shorten towards the poles, where their length becomes zero. This is shown diagrammatically in fig. 11. The horizontal lines represent to scale the length corresponding to *ten* degrees of longitude on every tenth parallel, and they divide NE to show on the same scale the length of each 10 degrees of the meridian. In Table II the length of 1 degree of parallel is given, chiefly for every tenth parallel. The figure and table, of course, direct attention to the convergence of the meridians from another point of view.

TABLE II

At Latitude (N. or S.).	Length of 1 degree of Parallel in Statute Miles.
0 degrees	69·17
10 ,,	68·13
20 ,,	65·03
30 ,,	59·96
40 ,,	53·06
50 ,,	44·55
60 ,,	34·67
65 ,,	29·31
70 ,,	23·73
80 ,,	12·05
90 ,,	0·00

Just as the length of 1° of meridian varies from part to part of the meridian, so there is a variation in the length of the degree along any given parallel. But in the case of the parallels the irregularity is so slight that they are to all intents and purposes true circles. Thus, the meridians being rather ellipses, with the polar diameter shorter than the equatorial, the earth approaches very nearly the figure which would be described by an elliptical hoop spinning about its shorter axis, a figure which is called an ellipsoid of revolution, or spheroid. We can sum up our knowledge of the figure of the earth by describing it as an *oblate spheroid* or *ellipsoid of revolution* of about the following dimensions:—

Equatorial semi-diameter, a ... 3963 statute miles.
Polar semi-diameter, c ... 3950 ,, ,,
Oblateness or flattening, $\frac{a-c}{a}$, $\frac{1}{300}$.

The number of parallels and meridians which are shown on globes and maps depends on the scale. On large scale maps they may be drawn every ten minutes. On atlas maps and globes they may only be drawn for every 10 degrees or more.

To move north and south at a point on the earth it is necessary to move along the meridian; while to move east and west the road lies along the parallel. These directions are at right angles to each other. We must realize what this means on the sphere. Clearly, on the globe this is only true *at* the point. As soon as the given point is left, the bend of the parallel turns the direction along it away from that at right angles to the meridian *at* the point. Also, while the planes of the meridians and parallels are at right angles, the *meridian itself* is not at right angles to the plane of the parallel.

Horizon.—To a dweller on the earth the ground in his neighbourhood appears to be flat, if he neglects the diversity of hills and valleys. This flat surface appears to be bounded by the observer's horizon. But there is no flat space on the globe, though it is possible to think of an indefinitely small part of any globe as flat. The apparently flat surface of the earth, or the indefinitely small flat surface at a given point, to be more exact, is called the horizontal plane at the point. Extended, this indefinitely small flat surface obviously becomes the tangent plane to the globe at the point, and this is parallel to the plane of the small circle which, as we have seen above, is the visible or *sensible* horizon at a point. Thus we have a true horizontal, or true horizon, at each point on the earth, and a sensible horizon, and the sensible horizon is below the true horizon (see fig. 4). In making his observations on board ship at sea, the

ailor uses the sensible horizon, and since he is on ıe bridge of the vessel, well above sea-level, the ensible horizon is well below the true. The angular istance of the sensible horizon below the true is alled the *dip of the horizon*. In the case of a man f 6 ft. high, the sensible horizon is about 3 miles istant from him, at nearly 2 minutes of angle below ıe true horizon of his eye.

The vertical at any point is at right angles to the orizontal plane, or to the surface of the earth at the oint. If the earth were a true sphere, the vertical vould be in the same line as the radius of the earth t every point, and we shall assume it is so for our urposes. At any place the vertical can be determined as the direction in which a plumb-line hangs. The horizontal is defined as the plane at right angles o the plumb-line.

Meridians and parallels at a point on the earth are t right angles *in the horizontal plane* where they ross that plane, and there only.

The surface of the earth which is represented on lobes and maps is the surface of the spheroid, which s everywhere at right angles to the plumb-line. It iffers from the actual surface of the earth in that t takes no account of the diversities of the features f the surface of the earth. It is approximately the urface that would be presented by the earth if it were overed all over by a tideless sea. The surface of an levated tableland would be high above this surface, nd before it was transferred to a globe or map it vould be reduced to the size of a corresponding surace on the spheroid at sea-level. It is this figure f which we speak when we say the earth is a pheroid. It is the nearest regular surface to the ctual surface of the earth, but it is purely imaginary,

though it is very useful. The only absolutely accurate way to describe the shape of the earth is to say that it is a **geoid**, which means an earth-shaped figure, and implies that the shape of the earth is peculiarly its own, and that we do not yet know it completely.

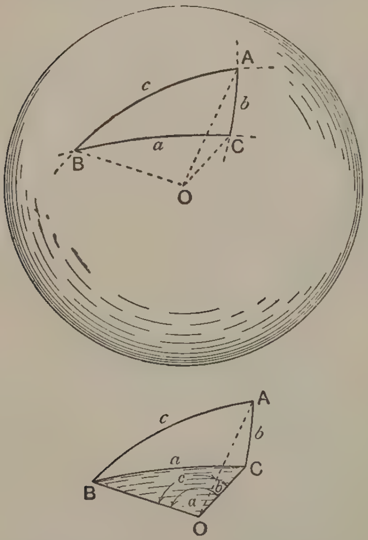


Fig. 12.—The lower figure represents the spherical triangle ABC cut out of the sphere along the planes of its sides. O is the centre of the sphere.

Spherical Triangles. — If any three points be chosen on the surface of a sphere, they can be joined by arcs of great circles, just as three points on a plane can be joined by three straight lines. In the latter case the figure produced is a plane triangle; in the former, it is a spherical triangle (fig. 12). In either case the triangle has three sides and three angles. In the case of the spherical triangle, the angles are the angles between the planes of the great circles which form the triangle, or, what is the same thing, the angles between the tangents to the great circles at the vertices of the triangles. The sides are curved, being arcs of circles, and we know that the lengths of these arcs are proportional to the angles which they subtend at the centre of the circles, that is,

in the case of the earth, at the centre of the earth. If R is the radius of the earth, then in fig. 12 we have for the sides of the spherical triangle ABC, AB = R.AOB, BC = R.BOC, CA = R.COA, O being the centre of the earth, and the angles AOB, BOC, COA being measured in *radians*. It is usual, however, to take the radius of the sphere as the unit of length in spherical trigonometry, and so to avoid using R. It is simple to convert into ordinary units when necessary by multiplying by the value of R, and it will be noticed, especially in dealing with what is called the celestial sphere, which has no fixed radius, that this is seldom necessary.

Just as plane trigonometry investigates and uses the relations which hold between the sides and angles of plane triangles, so the properties of spherical triangles are discussed in spherical trigonometry, the same trigonometrical ratios being employed in both. Though elementary spherical trigonometry is not much taught in schools, it is as easy as plane trigonometry; and since surveyors, and more particularly navigators, require to use its results, it will be to their advantage to learn its elements from a text-book on the subject. The formulæ of the two branches of trigonometry are very similar, but in spherical triangles trigonometrical ratios are used for both angles and sides. In fact, so far as spherical trigonometry is concerned, by the *side* AB of a triangle we really mean the angle AOB which AB subtends at the centre of the sphere. As an example of similarity in formulæ we have:

In plane triangles, $a/\sin A = b/\sin B = c/\sin C$.

In spherical triangles, $\sin a/\sin A = \sin b/\sin B = \sin c/\sin C$.

Suppose in fig. 12 A is the north pole, B, C

two places in latitude ϕ_1, ϕ_2, longitude l_1, l_2, then,

$$\begin{aligned} \text{side AB} &= c = \text{co-latitude of B} = 90^\circ - \phi_1. \\ \text{AC} &= b = \text{co-latitude of C} = 90^\circ - \phi_2. \end{aligned}$$

Angle A is the difference in longitude, $l_1 - l_2$, between B and C. Thus we are given two sides and one angle of the spherical triangle ABC, and can, as in plane trigonometry, solve the triangle for the third side or either of the other angles. Notice that, while the sum of the three angles of a plane triangle is two right angles, or 180 degrees, the sum of the three angles of a spherical triangle is always greater than two right angles by a quantity called the spherical excess, because the three angles are in *different planes*. Hence we cannot, having found two of the angles, subtract their sum from 180 degrees to get the third. The solution of the triangle in this case would give the length of BC, that is, the great circle distance, or shortest distance, from B to C. It would also give the angles BC makes with the meridians at B and C (the great circles, AB, AC are the meridians); that is the direction or bearing of B from C and of C from B.

CHAPTER II

FINDING POSITION ON THE EARTH

In order to use the information we have now acquired it is necessary to be able to apply it definitely to the earth. There is, however, nothing on earth to enable us to do so. For example, if one visits the south pole, one finds nothing in sight but a vast expanse of sky and level snow. How do we

know there is a real fixed south pole, and how can we fix it?

Since nothing on earth is of any use, we must have recourse to things without the earth—the heavenly bodies. At different times of the night the heavenly bodies seem to occupy different positions in the sky, and, after a great deal of discussion, the conclusion has been reached that this is due to the movement of the earth, particularly to its daily rotation on its axis. We must, therefore, learn a little about the position and apparent movements of the heavenly bodies.

The Celestial Sphere.—We shall take it that the student knows in outline the apparent movement of the sun and stars, and proceed to deal with certain definite ideas which are necessary for our purpose. The sun and stars are at very great distances from us on the earth, and it is useful to think of them as fixed, or nearly fixed, on the inner surface of a great hollow sphere. The earth rotates on its axis inside of this imaginary *celestial sphere*, bringing different parts of it into our view in the course of the twenty-four hours.

If the axis of the earth be imagined to be produced, it will cut this imaginary sphere in two points—the north and south poles of the heavens. There will appear to be no movement at these points. The celestial north pole is within our view in this country, and there happens to be a conspicuous star near it, the pole-star, which appears to move very little. The pole-star, therefore, gives approximately the north direction in this country. Any other star appears to rotate in a circle about the pole-star. It is worth verifying this by the following simple device. Take a small table outside any fine starry night and

stick a pin in it near one side. Place the eye behind this pin, and fix a second pin at some distance from it, towards, and in line with a bright star well away from the pole-star. Leave the table as it stands for a couple of hours or so, and then fix a third pin in the table in line with the first and the star. Draw

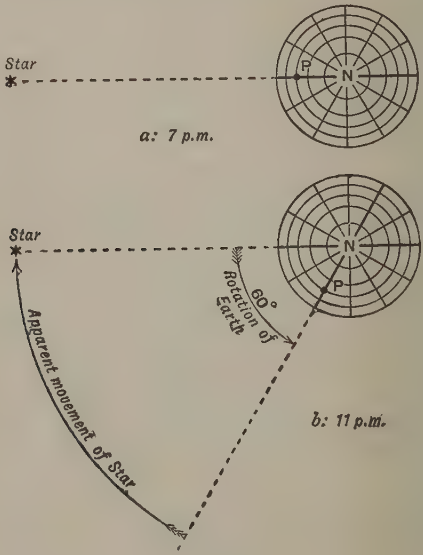


Fig. 13

lines from the first pin to the second and third, and measure the angle through which the star seems to have moved. From this decide the apparent direction of motion of the star, and the time it would take to return to its original position (fig. 13).

Fig. 14 shows the main stars visible in the northern hemisphere and their apparent direction of movement.

Corresponding to the meridians on the earth are the **celestial meridians.** These are the imaginary circles in which the planes of the terrestrial meridians, produced, cut the celestial sphere. They pass through

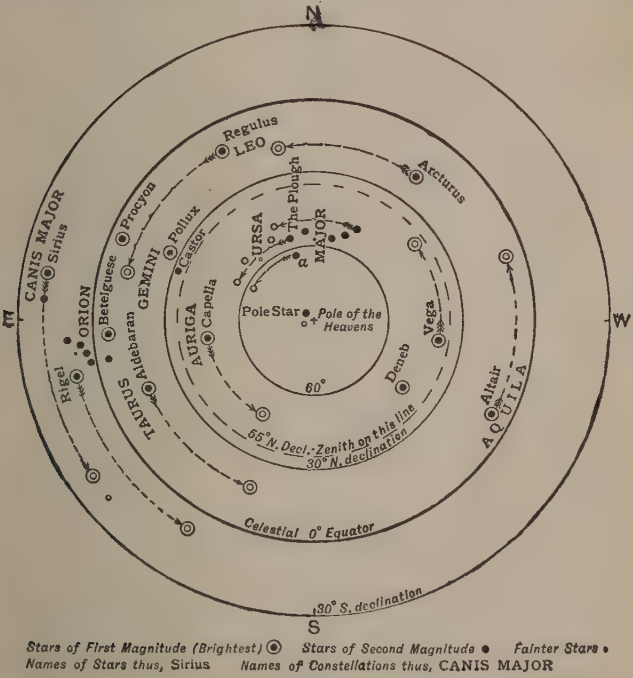


Fig. 14

the poles of the heavens. Similarly, the **celestial equator** is the imaginary circle in which the plane of the terrestrial equator cuts the celestial sphere. Just as latitude is the angular distance of a point on the earth from the equator, so **declination** is the angular distance of a heavenly body from the celes-

tial equator. The complement of the declination is the **polar distance** of the heavenly body (cp. co-latitude).

The sun appears to move round the earth, not on the celestial equator, but on a great circle inclined to it at an angle of nearly 23½ degrees, called the

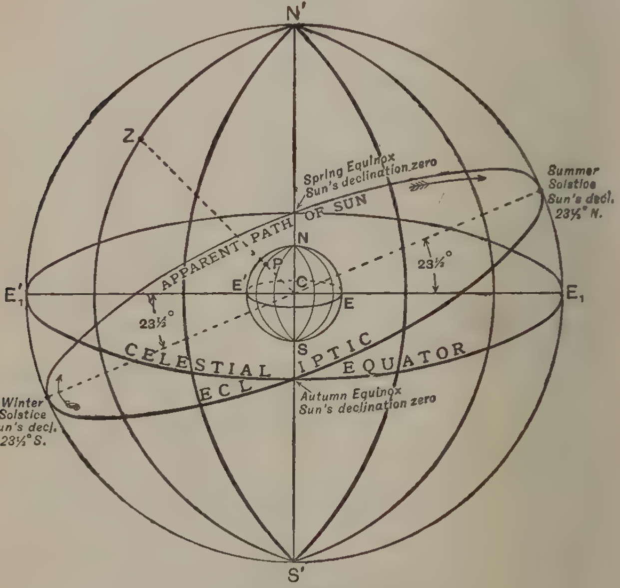


Fig. 15.—Celestial and Terrestrial Spheres

ecliptic. The ecliptic cuts the celestial equator in two points, called the **equinoxes.** About 21st March the sun is at one of the equinoxes, which is, therefore, called the spring or **vernal equinox.** Fig. 15 shows that at this time the sun is on the celestial equator, and its declination is therefore zero. So also, about 21st September, the sun is at the **autumnal equinox,** and is again in zero declination.

Just as the meridian of Greenwich is the starting-point for numbering off the terrestrial meridians, so the vernal equinox is the point on the celestial equator from which celestial meridians are numbered. The angular distance of a meridian east or west of this point is called its **right ascension**, which, therefore, corresponds on the celestial sphere to longitude on the terrestrial. Just as we can define the position of a point on the surface of the earth by means of latitude and longitude, so we define the position of a star by means of its declination and right ascension.[1] Parallels of declination are not circles in which the extensions of the planes of the terrestrial parallels cut the celestial sphere. They correspond to parallels of latitude, and are small circles parallel to the celestial equator.

We have seen that the earth is not really a sphere, although for our purposes we shall introduce no inaccuracy of importance by regarding it as such. The celestial sphere, being purely imaginary, is a true sphere. Its diameter is not fixed or definite; we think of it only as something enormously greater than the earth. The sun is about 93,000,000 miles distant from the earth, but this is not the radius of the celestial sphere. The stars are very much more distant from the earth, so much so that the sun would *appear* to move among them (if we could see sun and stars at the same time), just as a house near at hand appears to a passenger in a railway train to move across the hills that form the more distant background of his view. We must, however, distinguish between *stars* and *planets*; the latter, with which we have no concern at present, being much nearer to the earth than the former.

[1] *Celestial* latitude and longitude are quite different from declination and right ascension.

Zenith and Horizon.—We talk of the point overhead, or vertically above us, without remembering that the earth is not flat but curved. We mean by the *vertical* the direction at right angles to the ground.

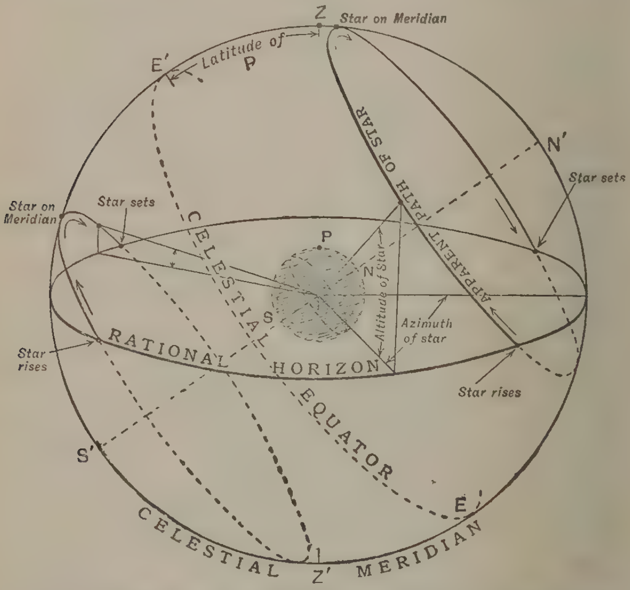


Fig. 16.—Celestial Sphere with Paths of Stars. Stars are invisible or below the horizon in the parts of their paths indicated by dotted lines. Z is the zenith of P on the earth, and the meridian of P is in the plane of the paper (Z′S′N). N′,S′ are the celestial poles. Note that E′Z, the altitude of the zenith above the celestial equator, is the latitude of P.

But what does the term mean in reference to the spherical earth? Geometry teaches that every radius of a sphere is at right angles to its surface. The vertical at any point on the earth, therefore, is the continuation of the radius joining that point with the centre of the earth. The point where this con-

tinuation meets the celestial sphere is called the zenith (Z, fig. 16).

The horizontal is at right angles to the vertical. The horizontal at a point P on the earth lies, therefore, in the plane tangent to the earth at P.

The *horizon* we usually regard as the circle which limits our vision on a "flat" surface, as at sea. We usually think of it as on the same level as our eye. More precisely, we may take it to be the circle in which the horizontal plane cuts the celestial sphere. It is usual in astronomy, however, to regard the horizon as the great circle of the celestial sphere at right angles to the vertical. This is called the **rational horizon** (see fig. 16; cp. Chapter I, p. 16).

Altitude and Azimuth.—Figure 16 shows how a heavenly body appears to move in the sky. It rises and proceeds to move higher and higher in the sky until it reaches the meridian. Then it sinks lower and lower until it reaches the horizon, and disappears from view or sets.

The angular distance of the heavenly body above the horizon is called its altitude, and the altitude of any star varies from zero at the points where it crosses the horizon to a maximum value where it crosses the meridian. The greatest altitude of a heavenly body is its meridian altitude. The sun is at its greatest or meridian altitude for an observer in the northern hemisphere when it is due south, near mid-day. A star (fig. 16, right hand) may be due north or (left hand) due south when at its maximum altitude.

The heavenly body not only moves away from the horizon; it rises at one point of the horizon, sets at another, and in the meantime its motion has carried it round above the horizon from one point to the other. This is called **motion in azimuth.** The

angular distance of the body round the horizon from the meridian is its **azimuth.**

Observations of the Sun and Stars.—In fig. 17 A represents a star, P, Q two points on the surface of the earth. Then from P the star A is seen along the line PA, from Q along the line QA, and these lines are not in the same direction; their direction differs by the amount of the angle PAQ. B is another star much farther from the earth, and the difference between the direction of B from P and Q is PBQ, a much smaller angle than PAQ. The nearest of the heavenly bodies we are concerned with is the sun, and the sun is so distant that the angle at it corresponding to PAQ or PBQ is practically unmeasurable. Hence we can assume that if you look at the sun or a star from any two points on the earth, you will look along parallel lines. In another way, we may say that rays of light reaching all points on the earth from the sun or a star are parallel. This, as we shall see, greatly simplifies the use of the heavenly bodies for geographical observations.

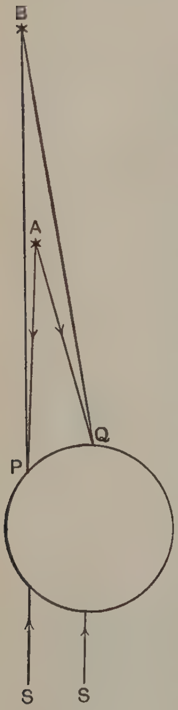


Fig. 17

But these rays of light pass from the emptiness of outer space through our atmosphere to reach the earth. The upper layers of the atmosphere are rare, the lower denser and denser. Hence the light suffers *refraction* (see any good textbook on elementary physics) as it passes through the atmosphere. The

effect of this is to increase the apparent altitude of any heavenly body as observed on the earth (see fig. 18). A star a little below the horizon is visible as if it were above it (C, fig. 18). The lower the heavenly body the greater the thickness of air its light has to traverse to reach the earth. *Astronomical refraction*, as it is called, therefore, varies

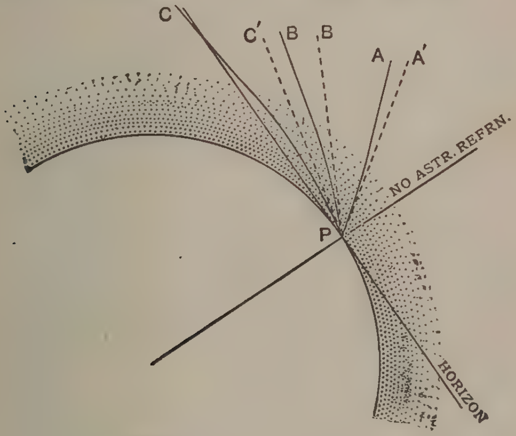


Fig. 18.—Astronomical Refraction

AP, BP, CP, paths of light from stars to earth.
A′P, B′P, C′P, apparent directions of stars from P.

from zero for stars in the zenith to a maximum for stars near the horizon. All observations of the altitude of heavenly bodies have to be corrected for refraction. The corrections are found in tables, but they are uncertain for low altitudes. They vary as the state of the atmosphere varies, and so they have to be adjusted for the temperature and pressure of the atmosphere at the time and place of the observation. In choosing stars for observing, therefore, choose them at as great altitude as convenient,

in order that the astronomical refraction may be as small and certain as may be.

INSTRUMENTS

The instruments employed in geographical observations of the sun and stars are the **theodolite** and the **sextant.** The former is the more important. Descriptions of these instruments are of little use, and it is essential that the student should see and handle, and, if possible, actually use the theodolite. He will find it necessary to learn the use of the vernier (or micrometer) by actual practice, or from a book on practical physics.

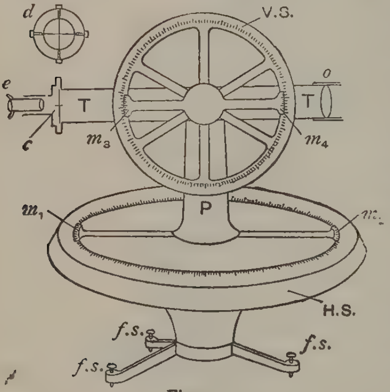


Fig. 19

Theodolites.—Theodolites differ a little in pattern and construction. The principle is the same in all, and is illustrated by fig. 19. Fig. 20 shows a photograph of a transit theodolite. In fig. 19 HS is a brass plate fixed firmly to a pedestal which rests on three foot-screws. By means of these the plate can be accurately levelled, two spirit-levels at right-angles to each other being fixed on the plate for the purpose. Standing vertically on the plate is a support P. This support is pivoted so as to turn round a vertical axis, and it carries as it turns two opposite verniers, m_1, m_2, rigidly fixed to it. These verniers run along a scale of degrees engraved on a silver

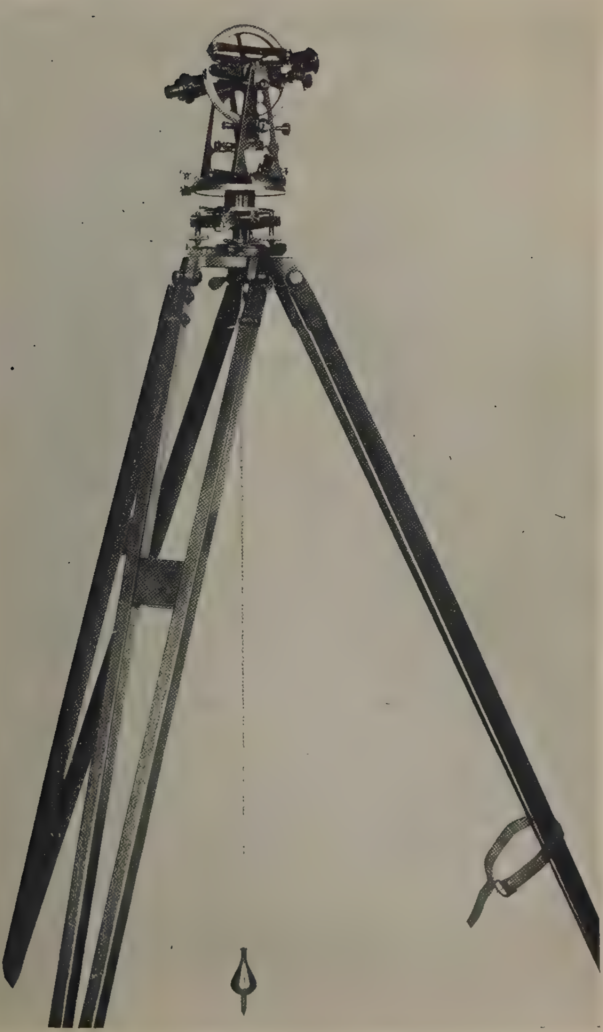


Fig. 20.—Transit Theodolite on rigid tripod stand

ring let into the brass plate HS. Fixed immovably to P is a double arm carrying verniers m_3, m_4. Supported by P, but pivoted so as to be able to turn in a vertical plane is a telescope T, to the axis of which is firmly fixed a vertical circle of brass, also with a silver ring divided into degrees. At the focus *c* of the eye-piece, *e*, of the telescope are two fibres of spider-web in the form of an exact cross, called the cross-wires (shown separate at *d*). These are fixed to an adjustable metal ring within the tube of the telescope, and are arranged with one wire vertical, the other horizontal, and the cross in the optic axis. The whole is mounted on a rigid tripod standing some 3 ft. high, the iron-shod feet of which may be pressed into the earth for security.

Suppose, now, we wish to take observations of a star with the theodolite. We level the horizontal plate, that is, we bring it into the horizontal plane, so that angles read on it are azimuths—angles measured round the horizon. Angles read on the vertical circle are at right angles to this; altitudes, measured from the horizon. We turn round the support P (with its verniers) and tilt the telescope T (with the vertical circle) to bring the image of a distant fine mark on the cross-wires, and then read the angular amount of horizontal turning and vertical tilt. The image of the star is now brought on the cross-wires in the same way, and readings again made. The altitude reading gives the altitude of the star direct. The difference between the azimuth angles gives the difference of azimuth between mark and star. We read both pairs of verniers, and take the mean, to avoid errors of reading and errors introduced by any imperfection of construction of the instrument.

The theodolite is an expensive instrument of great delicacy and precision. It should, therefore, be handled with great care, and lifted by the most rigid parts.

The Sextant.—The sextant is a more portable instrument. It is used to read both vertical and horizontal angles, but, unlike the theodolite, cannot be set to give both at the same time. As a rule, it is not mounted on a stand, like the theodolite, and cannot be fixed in a true vertical or horizontal plane. Hence it does not yield the precision of the theodolite. Its principal use is at sea in navigation, where the motion of the ship makes it impossible to use an instrument mounted on a stand, and it is mainly employed for taking the altitudes of sun or star.

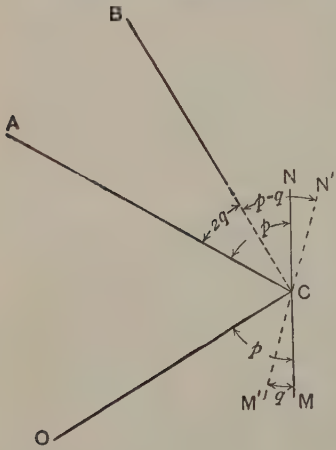


Fig. 21

Fig. 22 shows the principle of the sextant; fig. 23 is a drawing of an actual instrument.

The working of the sextant depends on the laws of reflection. In fig. 21 MN is a plane mirror perpendicular to the plane of the paper. If one looks into the mirror along the line OC, one will see in it an object A situated so that angle OCM is equal to the angle ACN (angle p). If, now, the mirror is turned about C into the position M′N′ (through angle q), A is no longer visible along the line OC,

but B is, angle OCM′ being equal to angle BCN′ $(p - q)$. Hence the angle ACB, which is equal to the difference of the angles ACN′ $(p + q)$ and

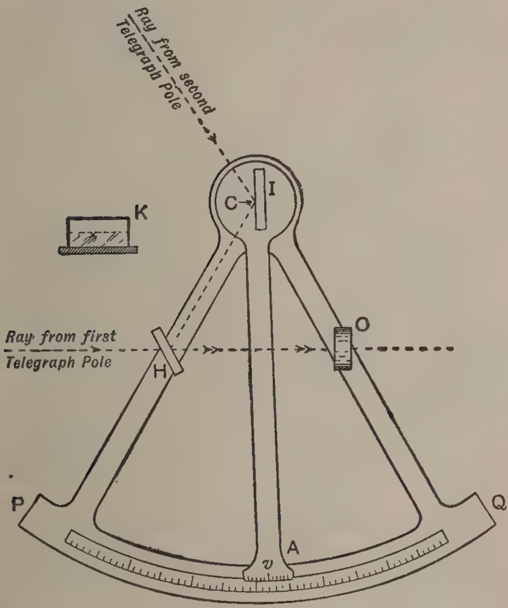


Fig. 22.—Simplified Plan of Sextant. Dotted lines indicate lines of sight

BCN′ $(p - q)$, is $2q$, or twice the angle through which the mirror has been turned.

Turning, now, to fig. 22, we see that the sextant consists of a sector of a circle PQ, rather more than a sixth of the circumference (hence the name *sextant*). Pivoted at the centre of the circle C is a brass index-arm IA, with a vernier v at its outer end. Mounted securely on this arm, with its face perpendicular to the paper and in the centre-line

of IA, and placed with its centre over C, is a plane mirror I, called the index-glass. The vernier *v* moves along a scale engraved on silver or platinum let into PQ. The zero is towards Q, and the scale is numbered up to 120 degrees or 140 degrees towards P. H is another plane mirror facing O, with the

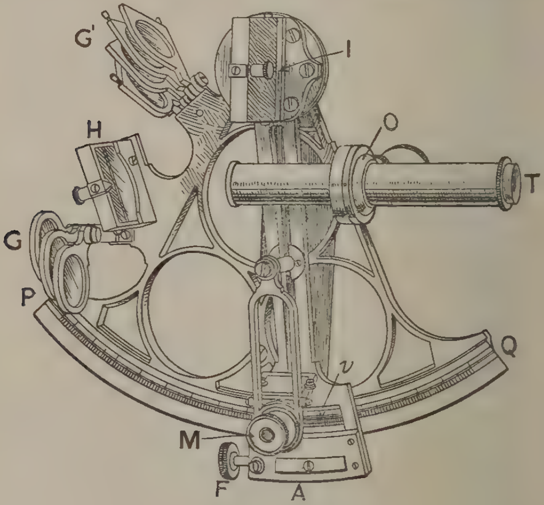


Fig. 23.—Sextant

GG' are shade glasses for use in observing the sun. M is a magnifying glass for use in reading the vernier.

lower half only silvered, as shown in elevation at K. This is called the horizon-glass, and is fixed so as to be parallel to I when the vernier is at the zero of the scale. At O is a ring which may be used as a peep-hole, or a telescope may be screwed into it.

The student will see that the line HC in fig. 22 corresponds to OC in fig. 21. The line of sight OH is such that in the lower half of H is seen the reflection

of C. If, now, one looks from O through the upper unsilvered part of H at some *distant* object, like a telegraph pole, and holds the sextant horizontal with the vernier at zero, one sees in the lower half of the mirror the reflection of the same telegraph pole from I. If the two images do not exactly coincide, H is out of adjustment. By turning the arm IA, the image of an adjacent telegraph pole reflected from I can now be brought into coincidence with the one seen directly through the upper half of H. On the reasoning based on fig. 21, the angular distance between the two telegraph poles is twice the angle through which the mirror has been turned. So the scale on PQ is marked to read *twice* the angle through which the index-glass has been turned.

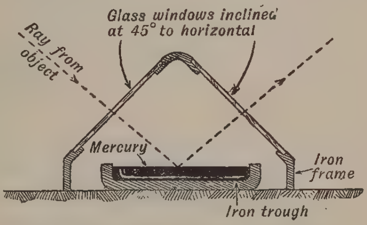


Fig. 24.—Section of Artificial Horizon in use

At sea the sextant (held vertical) is used to "bring down" the sun or a star to the visible horizon in order to get its altitude. On land it is seldom that one can get a good regular horizon: hills, woods, and the like get in the way. To obviate this difficulty the artificial horizon is used. This is merely a horizontal reflector. It is difficult to get a glass reflector dead flat throughout its area, so the horizontal surface of mercury in a shallow trough is used. This is protected from being ruffled by the wind by means of a glass roof (fig. 24). The image of the heavenly body is brought into coincidence with its reflection in the mercury. Fig. 25 shows that the angle read is *twice* the altitude (h).

Determination of the Latitude of a Place.—This can be done simply, but very roughly, by observation of the altitude of the pole-star. The student should work the matter out for himself by a diagram on the same plan as fig. 28. He will find that if the pole-star were exactly at the celestial north pole, the altitude of the pole-star would be equal to the lati-

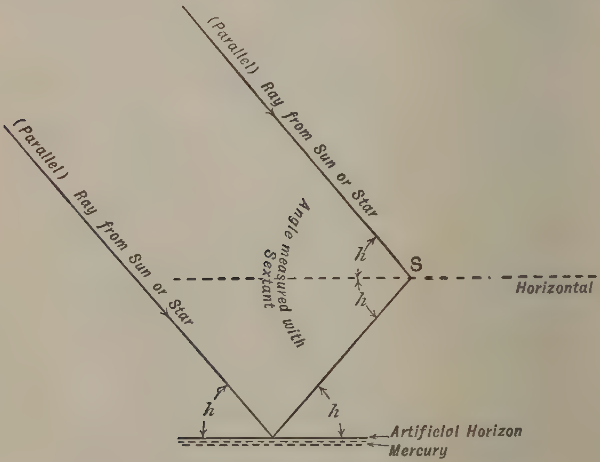


Fig. 25.—Use of Artificial Horizon. *h*, Altitude of sun or star

tude of the place. This method is seldom used in practice, because the pole-star is rather more than a degree from the pole, and the simple method gives an error of that amount.

The method generally adopted, except in very accurate work, is to take a meridian altitude of the sun or of a star. A star is always better to use than the sun, because it is impossible to be sure of having the centre of the sun at the intersection of the cross-wires. If the sun is employed, one reads the altitude

of the upper or lower limb (i.e. top or bottom), and applies the semi-diameter (angular) of the sun to correct the altitude to that of the centre. A method more often adopted, however, is to take a series of readings, alternately, of the upper and lower limb, each being taken the same number of times. Half the readings are too large and half too small by the semi-diameter of the sun, but as the mean only is used, the large and small balance and cut out the error. But the

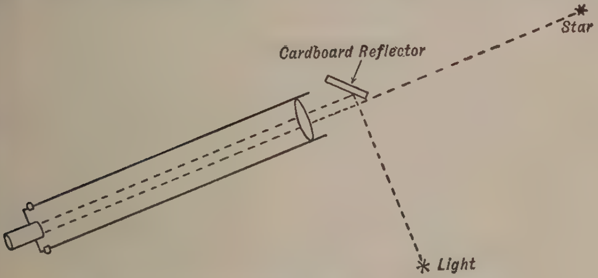


Fig. 26.—Illumination of Cross Wires of Telescope at Night

best and most accurate results are obtained by taking observations of a rather faint star, which in the field of the telescope has the appearance of a point of light. The star chosen should have an altitude of not less than 40 degrees, to avoid uncertainty of astronomical refraction. It should not be a very bright, dazzling star. The best plan is to observe several *pairs* of stars at about the same altitude, one of each pair being to the north, and one to the south. The reason is the uncertainty of astronomical refraction. If a pair of stars are taken, one N. and one S., and one makes the latitude too great because of refraction, the other will make it too small by about the same amount. The fact that star observations are made at

night is an advantage, because the state of the atmosphere is then more uniform than by day, and the effects of refraction are more regular. But at night the cross-wires of the instrument cannot be seen unless illuminated by some device such as that shown in fig. 26.

It is impossible to make sure that the altitude observed is the greatest, i.e. the altitude of the heavenly body when actually on the meridian. The observations should begin a minute or two before the

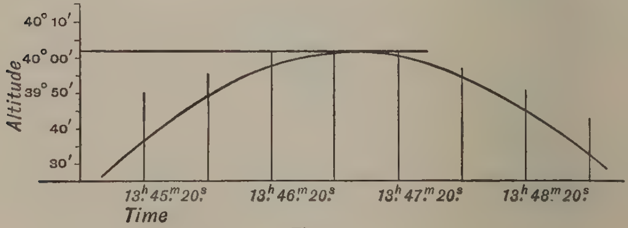


Fig. 27

star (or sun) is due to cross the meridian, and should go on for a little after. A set of several altitudes will be obtained. Either the greatest can be used, or the altitudes can be plotted on a graph against the time (fig. 27), and the time and amount of maximum altitude obtained from the graph. In taking an altitude the telescope should be set a little ahead of the heavenly body, and the object watched until it makes contact with the cross-wires by reason of its apparent motion. The time of contact should be noted.

The principle of obtaining the latitude by observation of a heavenly body is the same whether sun or star is used. In fig. 28 let NZS be the *celestial* meridian, O the earth, E′E the celestial equator, Z the zenith, H′H the horizon, S the sun or star. Then

$Z\hat{O}E$ = latitude, ϕ;

$S\hat{O}H$ = altitude of star (height above horizon), h;

$S\hat{O}E$ = declination of star (in this case north), δ;

$Z\hat{O}S = 90° - h$ = zenith distance of star, ζ;

and $\phi = \zeta + \delta$,

i.e. latitude is sum of zenith distance and declination.

Fig. 28 is drawn for the case when the place is in north latitude with the sun or star in north declination. The student

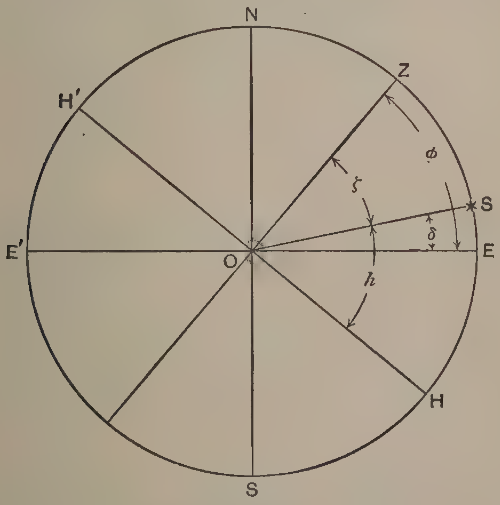


Fig. 28

should draw diagrams and work out the cases (1) when the place is in north latitude and the star is in south declination; (2) place in south latitude and star in south declination; (3) place in south latitude and star in north declination. He will then be able to arrive at the following general rule:

$$\pm\phi = \pm\zeta \pm \delta,$$

the correct sign being chosen as follows:

ϕ + if place is north of the equator (N. lat.).
ϕ − if place is south of the equator (S. lat.).
ζ + if star is south of zenith.
ζ − if star is north of zenith.
δ + if star is north of equator.[1]
δ − if star is south of equator.

As an actual example, let us take: South meridian altitude of sun at 2 p.m. by watch, Greenwich time, on 4th October, 1920, 44° 21′; thermometer, 50° F.; barometer, 30″.

$h =$	$44° \, 21'$
[2] Correction for refraction	$- \, 01'$ (always subtractive)
h (corrected)	$44° \, 20'$
Subtract from	$90° \, 0'$
$\zeta +$	$45° \, 40'$
[1] δ (2 p.m., G.M.T., 3/10/20) −	$4° \, 21'$
$\therefore \phi +$	$41° \, 19'$

That is, the place is in lat. 41° 19′ N.

It is to be noted that the transit of the sun (i.e. passage of the sun across the meridian) occurs at 2 p.m., Greenwich time. The place of the observation is, therefore, not on the meridian of Greenwich.

For very accurate determinations of latitude a slightly different procedure is adopted, with the object of getting more precisely the actual meridian altitude of the heavenly body. We cannot go into it; the principle is the same as that of the method given, which is usually employed at sea.

Longitude and Time.—The rotation of the earth on its axis brings the successive meridians under the sun, or under a given star, at successive times, and provides means of reckoning time and finding

[1] The declination of the sun or a star is to be taken from the tables of the *Nautical Almanac*, published yearly by the Admiralty. The value used is that for the time of the observation. The tables indicate whether the declination is north (+) or south (−).

[2] To be obtained from mathematical, astronomical, or navigation tables, and adjusted for temperature and height of barometer.

longitude. The two are intimately bound up together.

Successive transits of the sun or of a star on a given meridian take place every twenty-four hours, and fix the period of the day. The time when the sun is on the meridian of a place is noon at that place. The earth takes twenty-four hours to complete the 360 degrees of its rotation. In one hour it rotates through 15 degrees. Hence, since the earth rotates from west to east, when it is noon at Greenwich, it is an hour before noon on the meridian of 15° W., and three hours after noon on the meridian of 45° E. For this reason longitudes are sometimes given in time units instead of in angle units on the scale:

$$24^h = 360^\circ; \qquad 1^h = 15^\circ;$$
$$1^\circ = 4^m; \qquad 1^m = 15';$$
$$1' = 4^s; \qquad 1^s = 15''.$$

[h, m, s, = hours, minutes, seconds of *time*; °, ′, ″, = degrees, minutes, seconds of angle.]

	h.	m.	s.
E.g. long. 66° 24′ 15″ W. = long.	4	25	37
For 66° = 15° × 4 + 6° =	4	24	0
24′ = 15′ + 9′ =	0	1	36
15″ =	0	0	1
	4	25	37

In this way the longitude of a place is merely the Greenwich time of noon at that place. If the longitude is west, this is clear. When the longitude is east, noon occurs at the place before Greenwich noon. It is convenient for this purpose to reckon time not in two 12-hour periods, but in one 24-hour period from noon to noon. If noon to-day is 0^h, ten minutes before noon to-morrow is $23^h\ 50^m$.

		h.	m.	s.
So, e.g., long. 24° 47′ 45″ E. is in time		22	20	49
For, $24° = 15° + 9°$	=	1	36	0
$47' = 15' \times 3 + 2'$	=	0	3	8
$45'' = 15'' \times 3$	=	0	0	3
I.e. noon occurs at long. 24° 47′ 45″ E. before Greenwich noon by		1	39	11
Subtract from		24	0	0
∴ Longitude of place, or Greenwich time of noon at place is		22	20	49

It now appears that if we carry to a place a watch which keeps Greenwich time, in order to tell the longitude of the place it is only necessary to determine at it the instant when the sun is on the meridian. The longitude (in time units) is the time shown by the watch at this instant.

Local Time and Standard Time.—Noon at any place is the time when the sun is on the meridian. It occurs at the same time for all places on the same meridian, and at different times for different meridians. Time reckoned from this *local noon* is called *local time*. But it would be very confusing if at every place local time were used. It is, therefore, customary to divide the earth into *time zones*. These time zones are bounded by meridians 15 degrees of angle, or one hour of time, apart in longitude. At all places within the same time- or hour-zone clocks are set to keep the time of the central meridian of the zone. This time is called *standard time*.

In Great Britain Greenwich time is used; in Ireland, Dublin time, which is 0 hour 25 minutes 2·1 seconds slow on Greenwich. In North America standard time is employed, but the boundaries of areas in which a given time is kept are somewhat irregular, in order that there may be few inconvenient

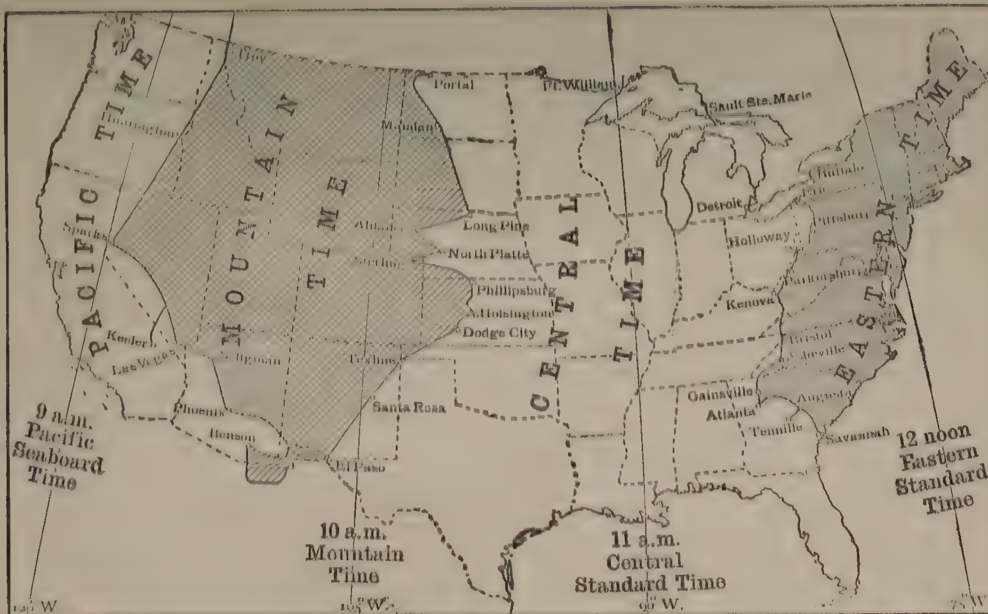


Fig. 29.—Time Zones in the United States

changes of time on railways and frequented lines of communication (see fig. 29).

We may consider here another question of time important in navigation. Suppose an airman sets out from Greenwich on Monday at midday, and flies westward round the earth, just keeping up with the apparent motion of the sun (i.e. at the rather unusual rate of about 650 miles an hour). It will be noon all the way with him. Will it be noon, Monday or Tuesday, when he arrives in Greenwich twenty-four hours later? It will be noon, Tuesday. When did the change take place? In the days of the first Spanish circumnavigations of the globe westward by the Horn, the voyagers were surprised to find that they had lost a day on their calendar when they returned to Spain. Thus ships sailing west have to add a day to the calendar when they get half round the world; ships sailing east have to drop a day. It is agreed that this shall take place at the "International Date Line", corresponding in general with the 180th meridian, which passes chiefly across the ocean. Thus on the west of Alaska it is Monday; when in Siberia, it is Tuesday. Siberia was peopled from the west, i.e. from the interior of Asia. Alaska at one time belonged to Russia. It was then Tuesday there, when across the border, in Canada, it was Monday. When the States took over Alaska, a day had to be dropped from the calendar. The deviations of the date line from the 180th meridian are due to this and similar reasons.

Solar Time.—The sun is not a perfect timekeeper. The student may prove this as follows. Take a board H, about 2 ft. long, 6 in. or more broad, and ½ in. or more thick. Draw a line AB (see fig. 30) along the middle of the board; with centre C, about an inch

from one end of this line, draw across the board circles with radius of 12, 13, 14 . . . inches. Fix a stick V, about 23 in. long and section 1 in. square, at right angles to the board over C. Drive a long pin or thin nail P into the end of this stick as nearly vertically over C as possible, and cut off the head of it, so that about an inch projects. This apparatus is practically the ancient gnomon, the earliest representation of the sextant. Set it outside on the ground as nearly as possible so that AB is in the north to south line, the upright to the north, and fix it so that it will not be overturned by wind

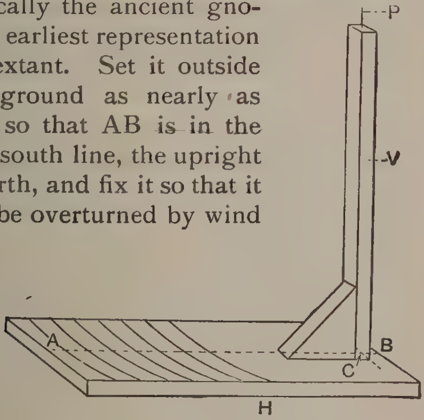


Fig. 30.—The Gnomon

or animals, and where it can remain for some time.

The instrument can only be used on sunny days, and in the winter half of the year the base-board may be found too short for use. The first step is to determine the meridian. Each day the shadow of the upright will be shortest when the sun is on the meridian. About noon, therefore, stand by and watch the shadow lessening. The circles will enable this to be done with some accuracy. Mark the outer end of the shadow of the pin when it is at its shortest. A line joining the mark to C will be the N. and S. line.

A better method of getting a point on the meridian is this. Say two hours before noon, if the shadow is on the base-board, the outer end of it may be near one of the circles. Watch until it is exactly on the circle, and mark the point, and note the time. Rather less than the same time after noon, return and mark the point where the outer end of the lengthening shadow crosses the *same* circle. The two points will be the same distance on either side of the meridian. The meridian will bisect at right angles the line joining the marks on the circle. By repeating this for other circles several determinations of the meridian can be obtained. If they agree closely, the line has been fixed with great accuracy.

Having drawn the north and south line on the base of the gnomon, visit the instrument every sunny noon if you can, for as long a period as possible, and note in a book the exact time at which the shadow of the pin crosses the meridian line. You may find on one day that this occurs at 12 o'clock by your watch, but it is very unlikely. This is partly due to the fact that your watch keeps Greenwich time. From a map, however, you can tell near enough what is your longitude, and thence find how much your local noon differs from Greenwich noon. You will find that the sun is not usually on the meridian even at the time of local noon, and that the interval between the time of local noon and the time of the sun's transit varies from day to day. It may vary by from less than two to ten minutes in the course of a month.

The moment of the sun's transit at a place is called Local Apparent Noon, noon by the clock keeping local time is called Local Mean Noon. The difference is called the Equation of Time. The equation of time is given in the *Nautical Almanac* for Greenwich noon

of every day in the year, together with its rate of change. The student should study pages I and II of the *Almanac* for each month of a year, to gain an idea of the amount and rate of variation of the equation of time throughout the year.

The time clocks keep is called Mean Solar Time. It is based on the *average* interval between successive passages of the sun across the meridian. The time kept by the sun is Apparent Time. It is indicated by the sun-dial.

Sidereal Time.—The stars may be used as time-keepers as well as the sun, and time as measured by the stars is *Sidereal Time.* Local sidereal noon is the instant at which the vernal equinox crosses the meridian.[1] There is no star at present at the vernal equinox, but in ancient times the vernal equinox lay in the constellation Aries (the Ram). It lies now in Pisces (the Fishes), but the name "First Point of Aries", is still the common name for the position in the heavens of the vernal equinox. It is denoted by the symbol ♈.

The sidereal day is nearly four minutes shorter than the solar. Suppose on Monday the earth is at 1 (fig. 31) when the sun is on the meridian. On Tuesday the earth will have moved to 2 by the time it has rotated on its axis once, and the meridian will be parallel to its position at 1. The sun will not now be on the meridian. The earth must rotate through the additional angle shown on the fig. before apparent noon occurs. Suppose some star was on the meridian on Monday at the same time as the sun. The stars

[1] Regarding the meridian as a complete circle, any heavenly body makes a transit, or crosses the meridian twice each day. Solar noon is the moment of upper transit of the sun. The lower transit at midnight is generally invisible. Sidereal noon is determined by the upper transit of the vernal equinox. Both upper and lower transits of a star may be visible, only by telescope, of course, by day, e.g. the stars in the Plough (cp. fig. 16).

are so much farther from the earth than the sun that this star would again be on the meridian when the earth is in position 2. Thus if sidereal noon coincided with solar apparent noon on Monday, on Tuesday it would occur earlier by about 4^m, the time taken by the earth to rotate through the additional angle. The student may further remark that this provides the

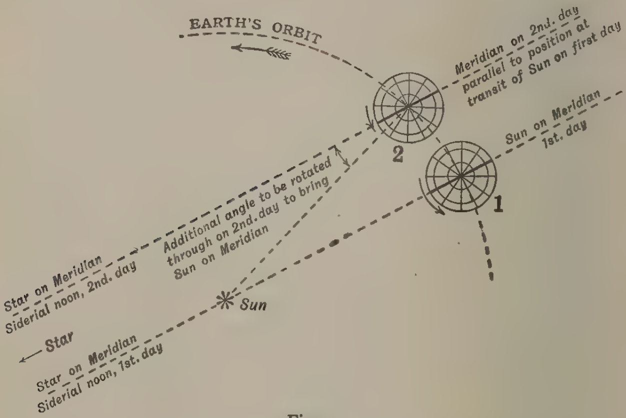


Fig. 31

explanation of the apparent motion of the sun among the stars.

The difference between the length of the sidereal day and the solar day mounts up to one sidereal day in the year. Hence the year contains 365¼ solar days, but 366¼ sidereal days. Sidereal time and solar time coincide at the vernal equinox. At other times sidereal time is fast on solar time. Mathematical and other tables, and the *Nautical Almanac*, provide means for converting sidereal time into mean (solar) time, and vice versa. The student should examine Chambers' or other tables for this.

Observations for Time.—In order to find the time, one may take the meridian altitude of the sun or a star as described under latitude above, but the *time* of transit is what is required. In the case of the sun, this is the time by the watch of apparent solar noon. To find the time of mean noon the equation of time must be applied to the observed time, and in order to find the equation of time at the moment of transit the approximate longitude must be known, i.e. local time must be known approximately.

Example.—

Time by meridian altitude of sun data, as, for example, on p. 40. Approximate longitude, 30° 15′ W.

	m. s.	h. m.
Observed Greenwich mean time of transit		2 00
[1] Equation of time at Greenwich apparent noon	11 13·59	
[2] Correction for longitude $0{\cdot}76^s \times 2\frac{1}{60}$	1·53	
[3] Equation of time at moment of observation	11 15·12	− 11
∴ Greenwich mean time of local mean noon		1 49

I.e. local mean noon occurs at 1.49 by the watch (Greenwich mean time), or local mean time is $1^h\ 49^m$ slow on Greenwich.

Observation of a star is a little more complicated, because we must use sidereal time. Solar and sidereal time agree at the vernal equinox. At other times they disagree. The amount of difference is given in the *Nautical Almanac* for each day on p. 2 of the section for each month as Sidereal Time (at Greenwich mean noon). Since this increases 9·86″ for every hour after Greenwich mean noon, the approximate longitude must be known in order to find the

[1] From *Nautical Almanac*, 1920, October, p. 1.

[2] Longitude is 30° 15′ W. = $2^h\ 01^m$; rate of variation of equation of time in 1 hour is found from *Almanac*, and variation in $2^h\ 01^m$ calculated.

[3] Neglect the seconds, since the observation is taken only to minutes.

local sidereal time of *local* mean noon. A little consideration will show that the right ascension of a star is the local sidereal time at which it will cross the meridian.

Let us take, as an example of finding latitude and time by a star, an observation of α *Ursæ Majoris*. This is the astronomical designation of the "pointer" of the Plough nearer the pole-star (see fig. 14).[1] Its position is given in *N.A.*[2], 1920, p. 328. Since the R.A. and Decl. vary only by a few seconds, while we are working to minutes only, we shall use the mean place (foot of column, *N.A.*).

Example.—

Meridian Altitude of α *Ursæ Majoris* at 8.16 a.m. on 5th October, 1920, 69° 07′: star N. of zenith: longitude about 30° 15′ W.

1. *Latitude.* h = 69° 07′

Astronomical refraction 22″: neglect.

Subtract from	90° 00′
ζ	− 20° 53′
δ (*N.A.*, p. 328)	+ 62° 11′
ϕ	+ 41° 18′

Latitude 41° 18′ N.

2. *Time* (*a*) L.S.T. at L.M.N.

	h.	m.	s.
G.S.T. at G.M.N. (*N.A.*, p. 11)	12	51	29
(*Note.*—5th October, 8.16 a.m., is astronomically 4th October, time 20.16.)			
Correction for longitude, 2^h 1^m at 9·86 seconds per hour	+		20
∴ L.S.T. at L.M.N. (nearest minute)	12	52	00

[1] The student will do well to refer to a popular or elementary book on Astronomy on the subject of this chapter generally, and in order to gain some acquaintance with the stars. For the latter purpose he is advised to procure and use the cheap and simple *Planisphere* by G. Philip & Son, Geographical Publishers, London.

[2] We use the following common abbreviations:—*N.A.*, *Nautical Almanac*; L.S.T., G.S.T., L.M.N., G.M.N., L.M.T., G.M.T., L.A.T., G.A.T., L.A.N., G.A.N.; L., Local; G., Greenwich; S., Sidereal; M., Mean; T., Time; N., Noon; R.A., Right Ascension; Decl., Declination. Other symbols as used earlier.

	h.	m.
(*b*) R.A. of star (*N.A.*, p. 328)	10	59
[1] Since R.A. is less than L.S.T. at L.M.N., add	24	
	34	59
L.S.T. at L.M.N.	12	52
∴ No. of sidereal hours and minutes after L.M.N. of moment of transit of star	22	07

	h.	m.	s.
(*c*) Reduction to M.T., 22^h (sidereal) (*N.A.*, 1920, p. 542)	21	56	24
07^m		06	59
∴ L.M.T. of instant of observation ...	22	03	(23)
Time of observation by watch ...	20	16	
∴ Time of L.M.N. by watch	1	47	

This observation makes the watch 1^h 47^m fast on L.M.T. The solar observation of example on p. 49 differs from this by 2^m.

Another method is that of *Equal Altitudes*. Some time, two to three hours, before the transit of sun or star (i.e. in the case of the sun, about 9 a.m.) the theodolite is set up, and the moment at which the heavenly body makes contact with the horizontal wire of the instrument noted. The instrument is left standing with the tilt of the telescope fixed. Shortly before three hours have elapsed after the transit the theodolite is turned round in azimuth, the altitude being unchanged, so that the object will come into the field of view. The instant at which the sun or star makes contact with the cross-wires is again noted. We have now the time at which a heavenly body reached a certain altitude in ascending to the meridian, and the time it reached the same altitude descending from it. The instant of transit is half-way between these times.

[1] Transit takes place at 10.59 L.S.T.; i.e. *before* L.M.N., which occurs at 12.52 L.S.T. by 1^h 53^m (*Sidereal* hours and minutes). But time is always reckoned *after* noon. Hence we must subtract 1^h 53^m to get the interval of time from the previous noon. It is simpler, and gives the same result, to work as above.

We therefore take the mean of the times observed as the time of transit, and proceed as in the examples just worked. In the case of the sun the declination changes somewhat between the observations, and for this a correction must be applied. Of course, the sky may be clear at the time of the first observation, but clouded when the second becomes due. The method gives fairly accurate results.

Neither of these methods is that usually employed. The second cannot be applied conveniently at sea for obvious reasons. The commonest method involves a slight knowledge of spherical trigonometry, and the student is referred to books on navigation, surveying, or astronomy for complete information. We shall indicate the principle of it here, and leave the reader to look it up elsewhere.

The **Hour Angle** (H.A.; t) of a heavenly body at a place on the earth is the angle between the meridian of the body and the meridian of the place. It is, therefore, measured in the same way as angles of Right Ascension or longitude (see fig. 32). When the heavenly body is on the meridian, the H.A. is 0 at upper transit, 12^h or $180°$ at lower transit. It changes uniformly on account of the uniform rotation of the earth. If we can determine the hour angle of a heavenly body at any time, we can tell, therefore, the time at which a transit of the body will take place, and so find the time of L.M.N. as before. To do this we must solve the spherical triangle NZB. NZ is the co-latitude, χ, of the place; NB is the polar distance, p, of the heavenly body; ZB is the zenith distance, s, of the heavenly body. We must, therefore, know ϕ; p we get from the declination extracted from *N.A.*; s we obtain from an observation of the altitude h, of the heavenly body. We solve the

spherical triangle for $Z\hat{N}B$, which is the same as E′OR, the H.A. of the heavenly body.

At sea the sun is usually observed for time about 9 a.m. Reference to the paths of heavenly bodies in fig. 16 will enable the student to see that at transit the body is moving horizontally across the meridian,

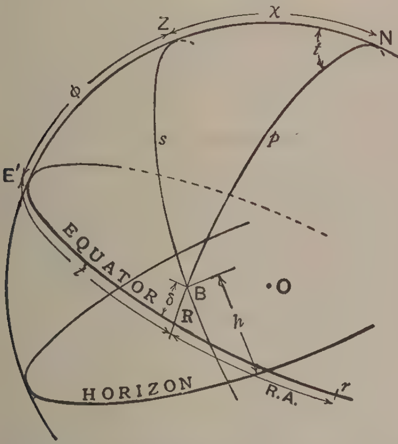


Fig. 32.—NZE′, Celestial Meridian of Place of Observation. NB, Celestial Meridian of Heavenly Body, B, cuts equator in R.

while half-way between the two transits the body is moving almost vertically. The altitude is changing more rapidly when the heavenly body is well away from the meridian than when it is near it, and, therefore, an observation for the time of an altitude is more accurate when the body is not near the meridian. This is why the method is that generally used.

Longitude.—We have seen how to find L.M.T. at any place. If our watch keeps G.M.T., we are able to tell the difference between G.M.T. and L.M.T. at the

place at which we have made an observation. For example, the *mean* difference by observation between the time of G.M.N. and L.M.N. at the place to which our two examples refer is: $\frac{1}{2}(1^h\ 49^m + 1^h\ 47^m)$, or 1^h 48^m. Therefore the longitude of the place is $1^h\ 48^m$ in time units, or, converting into angle units,

$$
\begin{aligned}
1^h &= 15^\circ \\
48' = 4' \times 12 &= \underline{12^\circ\ 00'} \\
\therefore \text{Longitude of place is}\quad & \underline{\underline{27^\circ\ 00'}}\ \text{W.}
\end{aligned}
$$

For the determination of longitude we must therefore (1) make an observation for L.M.T.; (2) know G.M.T.[1] We must now consider (2).

We have usually assumed our watches keep G.M.T. But often they only give the time to minutes, and that is why we have only worked to minutes in the examples. They may be good timekeepers, but they are not good enough for accurate determination of longitude. In order to carry time for determination of longitude special timekeepers, called chronometers, are carried at sea. These are very accurately made. The time can be read from them to a second, and they usually beat or "tick" half seconds. It is essential that they should go regularly. They are not kept at the right time; they are not even expected to keep time without varying. The important thing is that they should gain or lose time at a regular known rate, and that their error should be known at one time so that it can be calculated at any other. Chronometers are very delicate instruments. They are, therefore, kept with extreme care. When a ship is in port, every opportunity is taken to compare the time of the

[1] G.M.T. is usually employed in practice, but it will be clear to the student that L.M.T. for any other place would give the difference in longitude between the places. If the longitude of the place whose L.M.T. was used were known, then the Greenwich longitude of the place of observation could also be found.

chronometers with the time of observatories ashore in order to check their "rate", i.e. rate of gain or loss. When the ship remains at one place for some time, regular observations for time also provide a means of "rating" the chronometers. More than one instrument is carried, in order that greater reliability may be obtained by taking a mean of several time-keepers instead of depending on one only. Often one of the chronometers is regulated to keep sidereal time.

Changes of temperature and shocks upset the rate of chronometers. On shipboard these are avoided by providing a special case or even a special room for them. But when time has to be carried on land, they cannot be avoided, and chronometers are of little use. Very accurately made watches, called half-chronometer watches, are used instead, but they cannot be depended on like chronometers carefully kept on board ship. When a longitude is required, the watches are kept for at least a week at the place so that their rate may be as uniform as possible, and the rate is checked by nightly observations of stars for time.

Greenwich time can be sent out by telegraph, and the longitude of many places has been determined by this means. Of course the telegraphic time signals are only used to check and rate the chronometers before and during the observations, but they clearly increase the accuracy of the results. Until the advent of wireless telegraphy the use of the telegraph was limited to places with telegraph connections. Portable wireless sets have extended the employment of the method.

For direct methods of finding Greenwich time by observations of stars, students are referred to the books mentioned above.

Azimuth or Bearing.—The student will realize that observations are made in the planes of great circles. The angle between the meridian and a great circle is the *azimuth* or *true bearing* of that great circle. Thus in fig. 32 the angle NZB is the azimuth or true bearing of the star B at Z (or at the corresponding point on the earth). We shall measure azimuths round from north by east, or with the hands of a watch. Azimuths, therefore, run from 0° to 360°: 0° is north, 90° east, 180° south, 270° west; north-west is 315°.

It will be noted that the azimuth or true bearing of Z from B is the angle $(360° - N\hat{B}Z)$; and the angles NBZ and NZB are not equal. Thus the true bearing of any point A from any other point B is not usually the same as the true bearing of B from A. This is due to the convergence of the meridians.

The simplest way to find azimuth is to determine the meridian by transit of the sun or a star. Say we require the true bearing of B from A (and B should never be less than half a mile distant for accurate work). A small mark, such as a lath, should be set up at B. Set up and level the theodolite at A, and bring the mark at B on to the cross-wires. Read the horizontal circle. Say it reads 14° 51′. Swing the theodolite on to the sun or star, and read the horizontal circle when the heavenly body is at its highest point. Say the reading is 293° 17′. Then:

Reading on B	14° 51′
Since this is less than the reading on meridian, and the angle *from meridian to* B, not *vice versa* is required, add	360° 00′
	374° 51′
Reading on meridian	293° 17′
Azimuth of B at A	81° 34′

This is what is called a South Meridian Bearing (S.M.B.). It is reckoned clockwise round from south. To get the N.M.B., reckoned from north as above, we must add 180° (subtract 180° if the S.M.B. is greater than 180°). B, then, bears 261° 34′ from A. The student should draw a diagram for each case to keep him right.

From what goes before it will be clear that this is a very rough method. But returning to fig. 32, it will be seen that triangle BZN can be solved for the angle NZB, which is the bearing of the star B. If a terrestrial object C be included in the observation, we can read the angles to C and to B on the horizontal circle, and proceed as follows:

(1) Observed horizontal angles:

To star B	79° 14′
To C	217° 29′
Angle from B to C	138 15

(2)

Azimuth of star B (calculated from $\triangle$ NBZ) ...	114° 57′
Angle from B to C	138° 15′
∴ Azimuth of AB	253° 12′

CHAPTER III

THE MAKING OF MAPS—I

The Plan of the Map—Map Projection.—The map is the graph of the geographer. It enables him to summarize his knowledge of the earth by means of points, lines, and symbols or *conventional signs* laid down on paper to scale and in order.

It is, as a rule, not convenient to make the map of full size. A reduced scale has to be adopted. If

every distance measured on the map were a thousandth of the same distance measured on the earth, the scale of the map would be given by the **representative fraction,** 1/1000. This is sometimes called the "natural scale". On such a map 1 in. would represent 1000 in. on the ground, and 1 cm. 1000 cm., or, reducing to yards and metres, the scale would be 1 in. to nearly 28 yd., or 1 cm. to 10 m. Since there are 63,360 in. in the mile, the natural scale equivalent to 1 in. to the mile is 1 to 63,360, with representative fraction 1/63,360. Similarly, the "R.F." for the scale of 6 in. to the mile is 1/10,560.

If the earth be represented on a globe of 12-in. diameter, the scale of the representation is 12/7920 × 63,360, if we regard the earth as a sphere of diameter 7920 miles, which works out at 1 to about 42 million. It follows that every distance on the globe is a 42-millionth of the corresponding distance on the earth.

In this chapter we shall be concerned with maps of three kinds—world maps, atlas maps, and topographic maps. These differ mainly in the area they represent in a single map-sheet. If the area is large, the scale must be small, and the smaller the scale the less room is there on the map for representing the features of the ground. On a small scale map only the main features can be shown, and they cannot be shown in a detailed, but only in a generalized, way.

The term **world-map** is used of such maps as show the whole world, or not less than one hemisphere on one sheet. The information they can give is very generalized, for they are always on very small scales. At best they are little more than diagrams.

Atlas maps are, as the name suggests, such as occur in ordinary atlases. Each sheet shows a large

part of the surface of the earth, a country or a continent, extending over several degrees of latitude and longitude. The scales are, therefore, small, though larger than those of the world-maps; usually the scale is less than 1/2,000,000, or 1 in. to 30 miles. Compared with the world-maps, they are much less diagrammatic and generalized. A scale of miles is usually engraved on them, but such a scale cannot be used to measure distances with accuracy, for every map contains errors of construction, as we shall find, and the smaller the scale, and the larger the area represented, the more apparent these errors are.

Topographic maps are on much larger scale. They aim at representing the features or topography of comparatively small areas in greater detail and completeness than can be done on small atlas maps. The "inch-to-a-mile" map of the Ordnance Survey of this country, and the State maps of most civilized countries, belong to this class. In them the necessary errors of construction are not noticeable, and distances can be measured from them with sufficient accuracy.

These errors of construction of maps arise from the fact that the map is a representation of the curved surface of the spherical earth on a flat sheet of paper. A postage stamp can be stuck on the surface of a 12-in. globe[1] so as to lie as flat as on the corner of an envelope. A piece of paper 2 in. square, on the other hand, will not lie flat on any part of the globe, but if it be well wetted, it can be fitted to the surface almost as closely as the stamp. If the paper be twice as large, however, it cannot be fitted to the globe without creasing, even when wet.

The matter can be tackled from the opposite point

[1] If the student uses a globe of greater or less size to verify this statement and those which follow, he should use pieces of paper of size greater or less in proportion.

of view. Take a cheap rubber ball 3 or 4 in. in diameter, and cut out from it two spherical triangles of the same size. The best way to do this, so as to get triangles exactly equal and of suitable size, is as follows. Cut out of a stiff card a circular hole of the exact diameter of the ball, and mark on the edge of the hole four points 90 degrees apart (fig. 33). Support the card horizontally at a height above the table equal to the radius of the ball, less the thickness of the card, and lay the ball in the hole. With a needle make a puncture in the ball opposite each of the marks on the card. Now pass a fine knitting-needle right through the ball from one of the punctures to that opposite. Raise the card a little, and fix the ends of the knitting-wire so that the ball and the wire can be spun without the wire shifting. By turning the ball about the wire as axis, and holding the point of a pencil against it at one of the other marks on the card, a great circle can be drawn on the ball. Pass the knitting-wire through the other two punctures, and draw another great circle in the same way. Where the two circles cross puncture the ball again, pass the knitting-needle through, and draw a third great circle. The three great circles are at right angles to each other, and divide the ball into eight equal parts. Cut out two of

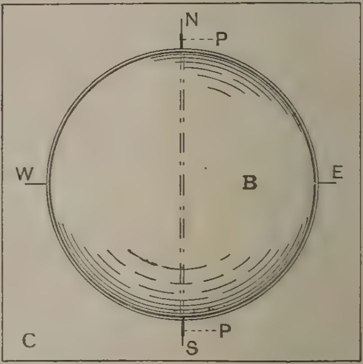


Fig. 33.—Card C with Ball, B, in Circular Hole. N, S, E, W, Marks on Card 90° apart. Needle, P, through Ball.

these, fit one on top of the other, and pass a needle through what seems to you the middle of the top one. The puncture will mark corresponding points on the two triangles, and it will be well to spot them with ink lest they cannot be found later.

Now cement one of the triangles down on a flat piece of wood, inside downwards, with rubber solution or other adhesive, placing a weight on it to keep it flat until the cement has set. The triangle does not fit naturally flat to the wood. Its curvature has to be squeezed out, and the squeezing produces change of shape or distortion. When the cement has set firmly, you can measure the amount of this distortion by measuring and comparing corresponding distances on the two triangles, such as the lengths of the sides, the distances from the middle of the triangle, which you have already marked, to the three vertices, and to the middle points of the three sides, &c. Make a table of four columns. In the first enter the lengths measured on the flattened triangle, in the second the corresponding lengths measured on the other. Put the difference in the third, and in the fourth the difference expressed as a percentage of the length in the second column. Your table will enable you to judge of the amount of distortion or error of construction to be expected in a map which represents an eighth of the surface of the globe.

The creasing in the one case and the measurement in the other indicate the amount of distortion produced in flat maps of the curved earth. The stamp may be taken to represent the case of a topographic map. The distortion is so slight in such a small area that wet paper is able to adjust itself to it. This is taken advantage of in the making of globes. The map of the world is printed on narrow gores, which, when

wetted, can be pasted on the surface of a sphere of the proper size without creasing. The larger squares of paper and the rubber triangle cut from the ball represent the case of atlas maps. The globe-maker could not paste a whole map of Asia of the proper size on to the sphere without creasing it.

This distortion means that the scale of the map is not the same at all parts of it. Hence the uselessness of a scale on a map of Asia, for example. The natural scale in such a case must be taken to indicate that, but for distortion, the map is on the same scale as it would be on a globe of that scale.

Since there must be distortion, the best thing to do is to make the distortion regular, and to adopt some plan of drawing maps so that the amount of distortion shall be made known. It does not follow that the amount of distortion is to be made as small as possible without reference to other considerations. Maps are required for various purposes. A motorist wishes, among other things, to be able to tell distances from place to place from his map. A man studying the United States may wish to be able to compare the area in which wheat is grown with that which produces cotton. His map must, therefore, represent areas correctly. It is not possible to get a map which shall represent all distances correctly, because otherwise the map would be free from distortion, but it does not follow that areas cannot be shown correctly. According to the purpose of the map, particularly if it is a small scale map, where the distortion will be very apparent, it is necessary to choose the plan of the map in view of the object for which the map is required. There are many plans or systems on which maps are drawn; they are called *Map Projections*. It is not a very fortunate name, and, in using it, it must not be

taken that the word "projection" has the definite meaning it has in geometry.

We have seen that every place has its parallel of latitude and its meridian. If we show how to place the meridians and parallels on the map, it will be sufficient, for these once drawn, points can be inserted according to their latitude and longitude. In treating the subject of map projections, therefore, we shall confine ourselves to discussing these circles. The map, with the meridians and parallels which it is intended to show drawn in, and nothing else, is called the graticule, or map net. We shall further confine ourselves to the discussion of projections which are commonly employed in the construction of maps in actual use.

Scale of Maps.—In general, when we compare a length on the map with the length on the ground which it represents, we shall find something like what is shown in figure 34. AB is a line divided into four equal parts. The line *ab* represents AB as a map might. The student ought to make a table of three columns. Enter in the first column the length of AB measured in inches and decimals of an inch. In the second enter the length of *ab*, and in the third the ratio of the length of *ab* to that of AB, or the natural scale of *ab* expressed as a decimal for easiness of comparison. In the second line of the table enter the same particulars for AE and *ae*, and repeat for AC, AD, &c. It will be found that the scale varies along the line *ab*. It is, therefore, not an accurate statement that *ab* is drawn to represent AB to a scale. The scale varies from point to point. If we wish to find the scale at any given point of *ab*, we must measure a very short distance on either side of that point, and, assuming that the scale is constant over that short distance,

compare the length with that corresponding on AB. If we found that the shorter the distance the more and more closely the scale approached some definite value, we should be justified in taking that value as the true scale at the point. For instance, supposing that by

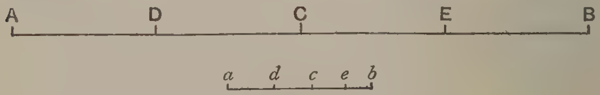


Fig. 34

taking several distances, each half the previous one, at the same point, we arrived at the following values for the scale: ·220, ·235, ·245, ·247, ·248, ·249. . . . It is clear that these fractions approach more and more nearly to ·250, and show no signs of going above that. The scale we should then assume to be ·25 *at that point*. When we talk of the scale at a point in a given direction, we shall mean the scale in this sense.

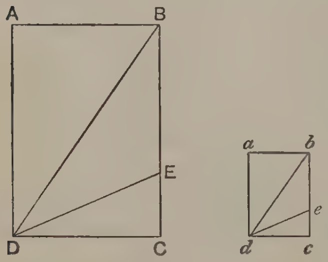


Fig. 35

Having selected a point on the map, we shall usually find that the scale along one direction from that point is not, in general, the same as that along any other direction. But suppose the scale is the same in two directions at right angles, then it will be the same in every direction. Thus in figure 35 the rectangle *abcd* is a drawing of ABCD, in which the scale is the same along *ab* and *ad*. Determine these scales as above, and confirm this. Then measure the scale along *db*, *de*, and along any other direction. It will be found the same throughout. Also, it will be

found that angles in *abcd* are equal to those they represent in ABCD. Hence, if in a map the scale in two directions at right angles are the same at every point, shapes of small areas at that point are correct, and angles about that point are correct.

Shape in Maps.—On the earth the meridians and parallels cross at right angles. It is of great value that on the map they should do the same. If they do not, it is obvious that the shapes of the land masses cannot be correctly shown. If the meridians and parallels are at right angles on the map, and if the scale at any point on the map along the meridians and parallels is the same, then the map is said to be **conformal** or **orthomorphic,** which means that it shows shapes of small areas correctly. It is easy to form a seriously mistaken opinion of the meaning of this, however. At any point of the map the scale may be the same along the meridians and along the parallels. But the scale cannot be the same at every point, otherwise the map would be a perfect representation of a part of the surface of the earth, which is not possible. **Orthomorphic maps** have the shapes of very small features correct, features so small that in them the change of scale cannot make itself noticeable. The small features at every point of a map may have their shapes correct, but at two points distant from each other the scales may be so different that the same area is shown at one two or three times as great as at the other. For instance, everyone is familiar with the map of the earth on Mercator's projection, on which most atlases show the British Empire in red. This is an orthomorphic map. The correct shape of every little feature is shown. A little bay on the north of Canada has its shape shown correctly just as a similar little bay on the Gulf of Mexico. But look at the

length of 10 degrees of parallel on the map. It is shown of the same size at 70° N. as at 30° N. It is, in fact, shown as of the same size all over the world. But we have seen (Table II) that 10 degrees of parallel are two and a half times as long at 30 degrees as at 70 degrees. Hence the bay on the north of Canada is drawn on two and a half times as great a scale as that in the Gulf of Mexico. And so, while the Mercator map is intensely flattering to the extent of the British Empire, since it exaggerates the size of British possessions in high latitudes like Canada, it does not show the shape of large land masses correctly, though it does so for small features.

Areas.—If scales were correct along meridians and parallels crossing at right angles on the map, areas would also be correct. But such a perfect map is not realizable. Areas, however, may be correct on the map, even if the meridians and parallels do not cross at right angles, and even though the scales along them are not correct. Thus in figure 36*a* we have a rectangle, bounded by meridians and parallels so close to each other that the convergence of the meridians is not noticeable. Standing on the same base, and between the same parallels, is a parallelogram, representing the same area as it would appear on the map in which the meridians do not cross the parallels at right angles. The areas of the two figures are equal. If every little area on the map is correct, then large areas are correct also, and the map is called an *equivalent*, or **equal area map.** In the **Bonne projection**, as we shall see below, the parallels are at their correct distance apart, and the scale along the parallels is the same at every point, but the meridians and parallels do not cross at right angles. Bonne's projection is equal area on the principle of fig. 36*a*.

Other means of obtaining equal areas are illustrated in fig. 36 *b*. ABCD represents the area on the earth; *abcd* the same area on the map. The two figures are of the same area. The student should verify this by measuring them. He ought, also, to determine the scale along the meridian and along the parallel, and find the relation between them. The figures $a'b'c'd'$, $a''b'c'd''$ are of the same area too, and if the meridians and parallels do not cross at

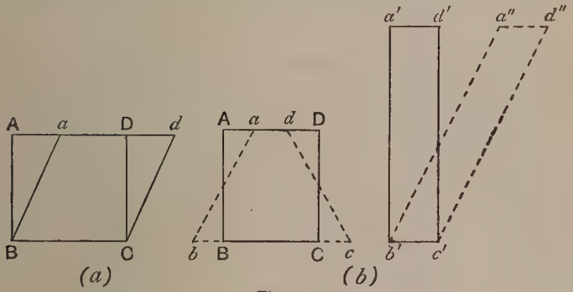


Fig. 36

right angles, the equal area property will be obtained if the relation which holds for $a'b'c'd'$ between the scales along the meridians and parallels holds for $a''b'c'd''$ between the scale along the parallel and along the line at right angles to it.

Developable and Undevelopable Surfaces. — A flat sheet of paper can be rolled round the curved surface of a cylinder. If the cylinder be in the form of a tube, the tube can be split up its length and unrolled to form a flat sheet. On the cylinder straight lines can be drawn parallel to the axis, and in no other direction. A curved surface, which can be unrolled flat like that of the cylinder, is said to be **developable**; to unroll it is to develop it. There is one direction in which

straight lines can be drawn on a developable surface, and the development takes place at right angles to that direction. The surface of the sphere, as we have seen, is not a developable surface. A second developable curved surface is that of a cone. Every shopman who rolls a conical bag out of a square of paper proves this in practice. In order to study the properties of a cone, the student should draw and cut out figure 37*a* to the dimensions given on it. The dimensions

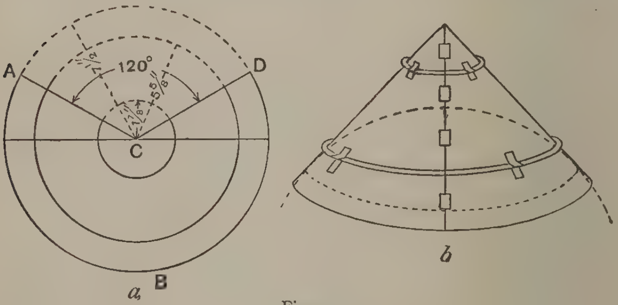


Fig. 37

are chosen in order to be able to apply the cone to a 12-in. globe. If the student uses a globe of different size, he should increase or decrease the dimensions in proportion. If he has no globe, a 3-in. or 4-in. rubber ball will do instead, and the dimensions should accordingly be divided by 4 or 3. Roll the paper exactly into the form of a cone, as shown in fig. 37 *b*, bringing the cut edges exactly together, and joining them with little pieces of gummed paper placed as in the figure. The cone produced will be a right circular cone, because its base will be circular (the student should prove this by standing the cone on a circle of 5-in. radius), and because its axis, the line joining the apex to the middle point of the base, is at right angles to

the plane of the base. Each of the arcs of fig. *a* has rolled into a circle on the cone. Cut out two rings of card, the inner radii being $1\frac{1}{4}$ in. and $3\frac{3}{4}$ in. These will fit round the cone along the circles which surround it. In order to make the cone more rigid, fix them in position with pieces of gummed paper as in fig. *b*. The student should now be able to arrive at the following conclusions, or to test them by his construction:—

1. Plane sections of a right circular cone parallel to the base are circular.
2. These plane sections of such a cone develop into, or become when the cone is unrolled, arcs of circles.
3. The radius, d, of any section of a cone by a plane parallel to the base is given by $d = r \sin \theta$, where r is the distance from the apex of the cone to the plane, measured along the sloping side of the cone, and θ is half the angle at the apex of the vertical section of the cone by a plane containing the axis (see fig. 38).

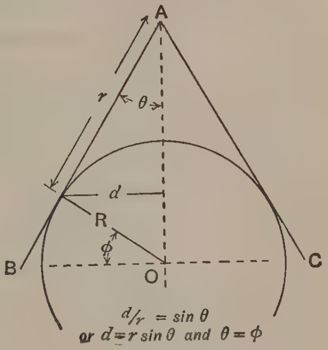


Fig. 38

4. The radius of any plane section of the cone is d; the length of the circumference is, therefore, $2\pi d$ or $2\pi r \sin \theta$. The radius of the circle of which the plane section develops into an arc is r, and the length of its circumference is $2\pi r$. The angle ACD, measured from CD

clockwise round to CA (fig. 37 *a*), is, therefore, $360° \times (2\pi r \sin\theta \div 2\pi r)$, or $360° \times \sin\theta$. Sin θ is called the constant of the cone,[1] usually denoted by n.

If the cone be now set on the globe, it will be seen to *touch* the globe along a circle, as suggested by the dotted lines in fig. 37 *b*. The cone is then called the tangent cone at this circle. If the axes of the cone and the globe coincide, we have the state of matters shown in section in fig. 38. The cone touches the globe along a parallel, and the latitude, ϕ, of the parallel is equal to the angle θ.

The main systems of projection have been suggested by three surfaces, the plane, and the curved surfaces of the cylinder and cone, the first being already flat, the other two developable. A plane will touch the globe in a point. If the plane be a piece of tracing-paper, it will be possible to trace the features from the globe on the paper, and in the immediate neighbourhood of the point an accurate enough map would be the result. At a distance from the point accuracy would deteriorate rapidly. A hollow cylinder of the same internal diameter as the sphere would touch the sphere along a great circle, and an accurate map could be made by tracing the detail on and very near the circle. A hollow cone would give a similar map along a small circle. Clearly the two latter maps would have the advantage over the first that they would be more extensive for the same accuracy. But projections are not made by tracings. The three classes of projections are **cylindrical, conical, and azimuthal or zenithal.**[2] Although the names of the

[1] In this case sin θ is obviously $5/7\frac{1}{2}$, since AC is $7\frac{1}{2}$ in. and the radius of the base is 5 in. This works out at 2/3, and the angle is 240°.

[2] Azimuthal projections are those suggested by the plane. The name is due to the

classes have a connection with the different surfaces, many of the actual projections are constructed without reference to them. They are of the conical, &c., type, but are modified, and become more or less conventional. We shall take the main examples in the order in which we have named them.

CYLINDRICAL PROJECTIONS

We shall adopt the following plan in regard to the scale of the map projections discussed. The scale of the map being decided on, we shall imagine a globe constructed to this scale, e.g. the scale being 1/42,000,000, the globe will be nearly 12 in. in diameter, or 6 in. in radius. In order to be able to assign any value that may be convenient to the scale, we shall denote the radius of this globe by R. Thus R/ρ, where ρ is the radius of the earth, will be the scale of the map. On the globe we shall have a perfect representation of the earth, neglecting the very slight distortion due to the fact that the earth is not quite a perfect sphere, for which we cannot allow here.

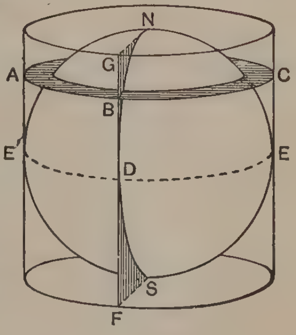


Fig. 39

Imagine a globe of radius R surrounded by a hollow cylinder of the same radius of cross-section and of height twice radius, so that the axes of sphere and

fact that the map shows correctly the bearings of all points on it from the centre. The name "zenithal" has no such clear connection, but is preferred because the other is hard to pronounce.

cylinder coincide. The cylinder will then touch the globe along the equator, and the arrangement will be as if the globe were set in a large pill-box, its poles flush with the top and bottom of the box, as in fig. 39. The planes of meridians will cut the cylinder in straight lines parallel to the axis, and the planes of parallels will cut it in circles intersecting these straight lines at right angles, as at FG, ABC, fig. 39. The cylinder will develop into a rectangle, and the lines represent-

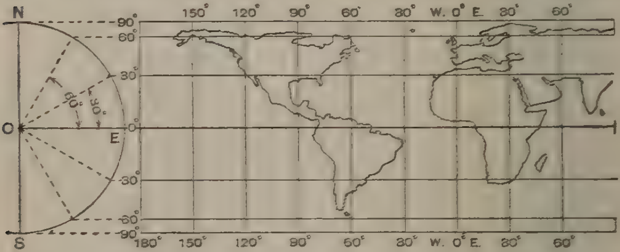


Fig. 40.—The World on the Cylindrical Equal Area Projection. NES is a meridian section of the globe. Compare with Fig. 41

ing meridians and parallels into straight lines at right angles with each other, as shown in fig. 40. The meridians will cut the equator at their true distance apart to scale, since the equator coincides on the globe and cylinder. All the parallels will be of the same length, and hence the scale will be exaggerated on all but the equator. On the projection the length of every parallel is $2\pi R$. The length of any parallel on the globe, we have seen, is $2\pi R \cos \phi$, ϕ being the latitude of the parallel. The scale of any parallel on the projection is, therefore, $2\pi R \div 2\pi R \cos \phi$, or, $\sec \phi$.[1]

[1] It should be clear to the student by now that the length of the circumference of a circle is proportional to its radius, and the ratio between the lengths of the circumferences of two circles is the ratio of the lengths of their radii. Since the ratio of the radii to each other in this case is $\sec \phi$, it is, therefore, at once apparent that the scale on the parallel is $\sec \phi$. If the student will remember this, it will save repetition.

By a well-known theorem in geometry the planes of the parallels cut off from both sphere and cylinder in this case equal zones. The area of the curved surfaces of sphere and cylinder are both $4\pi R^2$. The area on both figures between the plane ABC and the top, or between ABC and any parallel plane, such as that of the equator, are the same. Thus the area between any two parallels on the projection and the corresponding two parallels on the globe are equal; and since the meridians are equally spaced and divide up these areas equally, the projection is equivalent or equal area. It is known as the cylindrical equal area projection. From p. 67 and fig. 36 *b* it will appear that the scale along the meridians must be the reciprocal of the scale along the parallels, or cos ϕ. This projection is not used for maps to any extent. It is mentioned here because it depends on the important relation between the sphere and the circumscribed cylinder given above. The student will be able to construct it by following fig. 40, from which he can also study its properties.

MERCATOR'S PROJECTION

The only cylindrical projection the student will meet frequently in atlases is the **cylindrical orthomorphic**, otherwise **Mercator's projection**. The graticule of this projection is best constructed without reference to a cylinder. It is more or less conventional. Let us choose a scale that will fit the page of this book, say 1/500,000,000. Since the length of the equator is 24,000 miles on the earth, it will be 3·16 in. on the map. Draw a line E'E (fig. 41) of this length to represent the equator. On this scale we shall only be able to draw meridians at intervals of

30 degrees. The length of 1 degree of the equator is 69·17 miles (Table II, p. 15). The length of 30 degrees on our scale is ·26 in. Divide E′E into twelve equal parts, each of which should be ·26 in., and through the points of division draw lines at

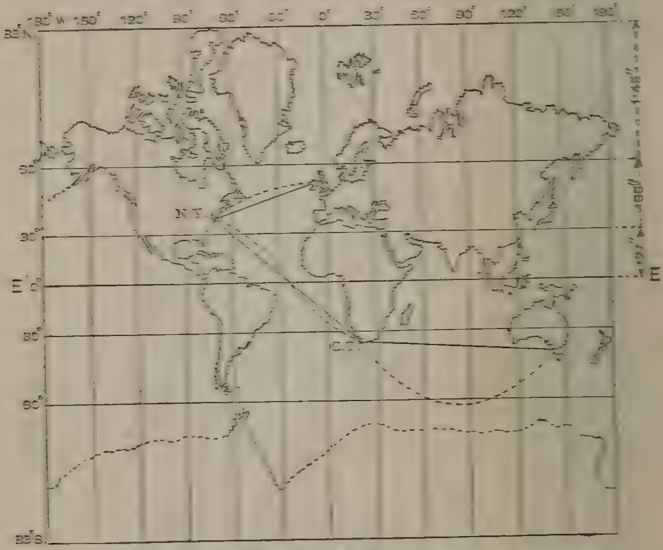


Fig. 41.—The World on Mercator's Projection: Scale 1 : [illegible]

On left, distances of parallels on map from equator. Broken curved lines are Great Circles. Straight lines are Rhumb Lines

right angles to E′E to represent meridians. As in the cylindrical equal area projection, the scale along the parallels will be *sec* ϕ. Since the Mercator projection is orthomorphic, the scale along the meridians must be the same. The scale of longitude must be more and more exaggerated the greater the latitude: hence the parallels will be drawn farther and farther apart as the poles are approached. Although we know

the scale along the meridians, it is not possible, with the amount of mathematics we can assume, to find the distance of the various parallels from the equator, and there is no simple geometrical construction to give it.[1] But in nautical and mathematical tables the distances of the parallels from the equator on the projection are given in nautical miles, that is, full size. These distances are called **Meridional Parts.** The parallels on the projection can be drawn from such a table, the distances being reduced to scale. The lengths used in constructing fig. 41 are given on the right of it. The student should note that on that figure the distance between the parallels of 60 degrees and 83 degrees is actually greater than the distance between the equator and the former. On both cylindrical projections the pole, which has no size, is represented by a straight line of the same size as the equator. The scale at the pole is, therefore, indefinitely large, and since the scale on the meridian at the pole is the same as the scale on the parallel, the parallel of 90 degrees will be at an infinite distance from the equator, and cannot be shown. On Mercator maps of the world, therefore, the polar regions have to be sacrificed, and it is usual to cut off the map at 83° N. and 75° S. The two cylindrical maps give moderate distortion in a belt round the equator. They do not differ greatly between the parallels of 30° N. and S., and hence either might be used for a map of Africa, which extends nearly equally on either side of the equator. This would be almost the only legitimate

[1] Students with some familiarity with the calculus will see that, the distance of the parallel of latitude ϕ from the equator being y, the scale on the meridian is

$$dy/Rd\phi = \sec\phi.$$

$$\text{Hence } y = \int R\,d\phi \sec\phi = \int R\,d\phi/\cos\phi = R\log_e \cot\left(\frac{\pi}{4} - \frac{\phi}{2}\right)$$
$$= 2.3026\, R \log_{10} \cot\left(45^\circ - \tfrac{1}{2}\phi\right),$$

transferring natural to ordinary logarithms.

use of the Mercator projection in atlas maps. It has, however, a much more important use in navigation. Take a straight line on the map, such as that joining New York and Cape Town (fig. 41). This line crosses all the meridians at the same angle on the map. Since the map is orthomorphic, and the meridians and parallels are at right angles, every

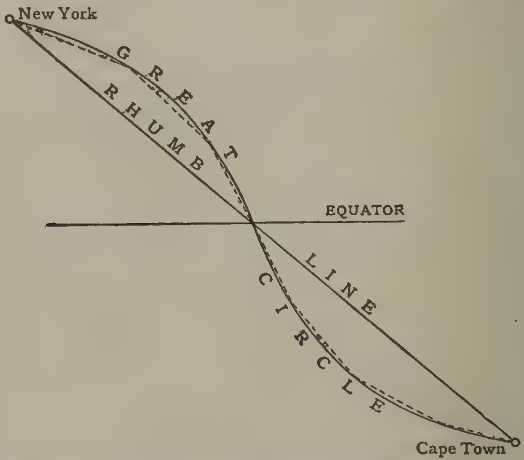


Fig. 42.—Great Circle, Rhumb Line, and Actual Course from New York to Cape Town, on Mercator's Projection.
Course sailed by ship - - - - - - - - - -

little angle on the earth is correctly represented on the map (see pp. 64, 65 and fig. 35). Hence straight lines on the map represent lines on the earth which cross the meridians at a constant angle, and have, therefore, the same bearing at every point on their course. These are called **Rhumb Lines** or **Loxodromes.** Before the modern aids to navigation had multiplied, it was a great convenience to the navigator to set out on an ocean voyage on a given

bearing, and to continue without change of bearing until he made his landfall; and rhumb line sailing was the rule. The rhumb line was easy to draw on the map, and the bearing of the line could be easily measured from the map by means of the protractor. In modern times it has become possible to save time by taking the shortest route, as far as practicable, between ports; in other words, to follow the great circle course. Great circles cannot be laid down on the Mercator chart easily, because they are represented by curved lines, as shown by the broken lines in fig. 41. The sailor follows the frequented great circle courses (as far as practicable) by following the instructions in books of sailing directions. The frequented ocean pathways are well known, and for each short rhumb courses have been worked out, giving the distance to be run on each course and the bearing of each course, so that the ship may sail along a series of chords of the great circle on Mercator's projection, as indicated in fig. 42. These "straight" courses are still along rhumb lines, so that the sailor can lay them off on his map with straight-edge and protractor. Hence navigation charts are still always constructed on Mercator's projection. The student will find further information on this subject in Chapter IX.

CONICAL PROJECTIONS

In the typical conical projections the parallels are arcs of concentric circles, and the meridians are parts of the radii of these circles. We saw that the cone will touch the globe along a parallel. When the cone is developed the circle of contact becomes an arc of a circle of greater radius, the arc being of

the same length as the parallel of contact. Such a parallel is called a *standard parallel*, and in conical projections there may be one or two, but not more, such standard parallels of true length.

The simple conical projection with one standard parallel is based on the tangent cone. Sometimes it is called the tangent conical projection, but this is a

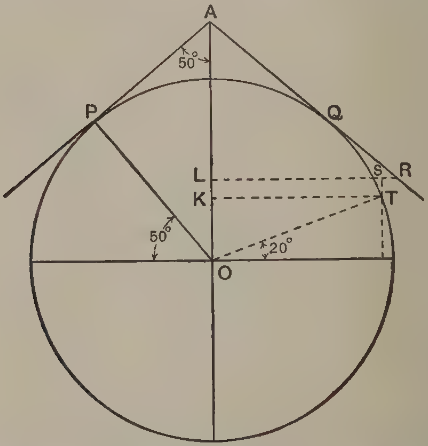


Fig. 43.—Meridian Section of Sphere and Cone tangent at 50° N. Scale 1 : 250,000,000. Lettering corresponds with Fig. 44

name to be avoided, because it is responsible for the misuse of the term "secant" conical for the one we take next. To construct geometrically the simple conical projection with one standard parallel, draw a circle to scale to represent the meridian, and at latitude corresponding to the middle of the map draw the tangent to the meridian AP (fig. 43), cutting the axis of the earth in A. The cone we wish to use is that which touches the sphere along the parallel of latitude ϕ, and since we shall have the greatest ac-

curacy along this parallel, it is well to take it about the middle of the map. It is clear that the radius of the parallel on the developed cone will be AP. As we have seen before, angle PAO is ϕ, OP is R, and AP = R cot ϕ. Hence, in order to construct the standard parallel, it is not necessary to draw fig. 43; but sometimes a graphical method is clearer than one by calculation. Now, with radius AP describe a circle, and lay off along this the distances on the standard parallel, corresponding to, say, 15 degrees of longitude, supposing it is decided to draw meridians every 15 degrees, and join the points of division to the centre of the circle. In order to draw the remaining parallels, we must lay off to scale along one of the meridians the lengths corresponding to 15 degrees of latitude, and through the points of division draw circles concentric with the standard parallel.

In this projection the scale is made true along the standard parallel and along the meridians, but not along any other parallel. Take the parallel of 20° N. The radius of this parallel on the earth is KT (fig. 43); on the cone it is LR, which is greater than KT by SR. By constructing a figure for the particular case, the student can show in this way that any parallel but the standard is too long. The scale is, therefore, too great along parallels on both sides of the standard parallel, and therefore areas, are shown too large, and the projection is not orthomorphic. In fig. 44 the student will note the north pole is represented by an arc. It is not so much exaggerated as in the cylindrical projections, but the south pole, if the map were continued so far, would be shown much bigger than the equator. Scales of parallel increase very much away from the standard parallel. The projection is not suitable for world-maps, but it is

suited for the representation on atlas maps of limited areas, especially such as do not extend far in a north and south direction. It is, however, rarely used.

The simple conical projection can be constructed with two standard parallels of true length, but it is not then derived from the tangent cone, nor from what is called the secant cone. To construct the graticule for this projection we must select the standard parallels to suit the extent of the area to be mapped. It is a good general rule that the standard parallels should be 1/7 of the whole extent of the map in latitude from the outside parallels. Having selected the standard parallels, calculate the length to scale of the parts of these parallels lying on one side of the central meridian of the map. Suppose we wish to make a map of western Europe, extending from 10° W. to 30° E., and from 35° N. to 70° N., on the scale of 1/25,000,000. The standard parallels will be 40° and 65° N., and the map will extend 20 degrees of longitude on either side of the meridian of 10° E., which will be the central meridian. From Table II, p. 15, take out the lengths of 1 degree of parallel for each of these latitudes and multiply by 20. On reducing to scale, it will be found the parallels will extend 1·49 in.

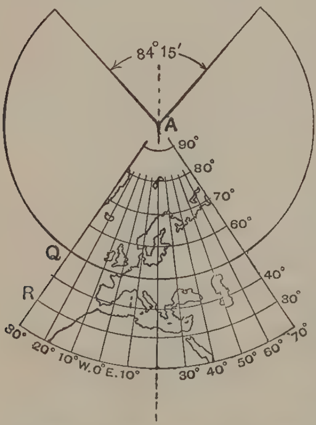


Fig. 44.—Map of Europe on Simple Conical Projection, with one standard parallel. Scale 1 : 250,000,000. Radius of Standard Parallel (50° N.), 0.84″; Distance apart of Meridians on Standard Parallel, 0.11″; Distance apart of Parallels, 0.17″–0.175″.

and 2·73 in. on either side of the central meridian. These parallels are to be at their true distance to scale apart. This distance on the map is 4·38 in., as the student should verify. Draw a line AB to represent the central meridian, and mark off on it a length AB of 4·38 in. (see fig. 45, which is not drawn to scale; it is intended that the student draw the map for himself). Through A and B draw lines AC, BD at right angles to AB of length 2·73 in., and 1·49 in. respectively. Join CD, and produce CD to meet AB produced in E. E is the centre of the circles which represent parallels, and the meridians are straight lines drawn through E, as in the projection with one standard parallel. EC is the meridian of 10° W. With centre E, and radii EA, EB, construct circles to represent the standard parallels, and complete the graticule precisely as in the case of the last. Using the points of intersection of meridians and parallels, sketch in the outline from a map of Europe in your atlas.

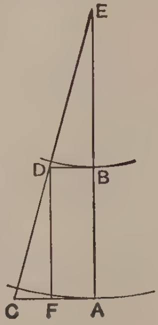


Fig. 45

Fig. 45 shows how the radii of the standard parallels may be calculated. Triangles EAC, EBD, DFC are similar. FC is the difference between AC and BD (in this case 1·24 in.); and DF is the distance between the two standard parallels (in this case 4·38 in.). Hence the ratio of AE to CA, and of BE to DB, is the same as the ratio of FD to FC, 4·38/1·24, or 3·53. Hence to get the radii of the standard parallels multiply 1·49 and 2·73 by 3·53. The radii are 5·26 in., 9·64 in., which differ by 4·38 in., as they should. Check this by measurement on your

drawing. This figure also shows the reason for the method of construction. Similar arcs of circles are proportional to the length of the radii. The construction makes the radii proportional to BD, AC, which are the lengths of 20 degrees of the two parallels.

The properties of the projection can be learned from fig. 46, which is drawn for an exaggerated case to

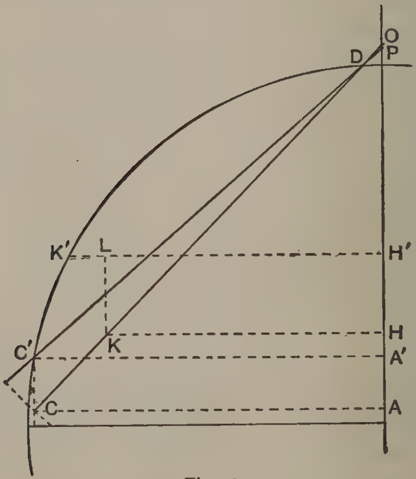


Fig. 46

bring out the facts plainly. There is shown a meridian section of the sphere. The standard parallels of the map pass through D and C′. DC′ would be a section of the secant cone by the plane of the meridian. On the map the parallels of C′ and D, being the standard parallels, are of equal size to these on the globe, but the distance between them is equal to the arc DC′, and so greater than the chord DC′ on the secant cone; therefore they come closer to-

gether on the secant cone than on the map, and the projection is not based on the secant cone. The section of the cone on which the projection is based is DC. The parallel of K′ on the sphere passes through K on the cone, the arc C′K′ and the line CK being of equal length. The radius on the sphere H′K′ is greater than the radius on the undeveloped cone HK by K′L. Thus the parallels lying between the standard parallels on the map are too short, and the scale is reduced. By extending the diagram, the student can show similarly that the scale on parallels lying outside of the standard parallels is too great. The scale on all the meridians is, of course, correct. The projection is, therefore, not orthomorphic nor equal area, the scale of areas on any parallel being the same as the scale of longitude on the parallel.

The projection is a very useful one, suitable for the representation of limited areas in atlas maps, and for topographic maps. For an extent of 20 degrees in latitude the maximum error of any length is about 1 per cent, and the expansion and contraction of paper with the variation of the moisture in the air produces about that much error in any printed map. The error, of course, does not increase with greater extension in longitude. The projection occurs infrequently in atlases, for maps of Europe, for instance; but if named on the map, it is usually called the "secant conical"

Either of these conical projections may be modified to give an equal area or an orthomorphic projection. This modification retains the one or two standard parallels, but the scale on the meridians is no longer true; in the case of equal area projections it is the reciprocal of, and in the case of the orthomorphic, the same as, the scale along the parallel at each point.

The equal area projection with one standard parallel is easy to construct. Remembering that the area of the sphere between the pole and the parallel of latitude ϕ is $2\pi R(1 - \sin\phi)$, or, if ψ is the co-latitude, $\sin\phi = \cos\psi$, and $1 - \sin\phi = 2\sin^2\frac{1}{2}\psi$, this area becomes $4\pi R^2 \sin^2 \frac{1}{2}\psi$. The area of the corresponding part of the projection is $n\pi r^2$. Hence $nr^2 = 4R^2 \sin^2 \frac{1}{2}\psi$. n, of course, is the constant of the cone. This formula holds for the radius of any parallel, including the standard parallel. For the standard parallel alone, radius r_0, latitude ϕ_0, co-latitude ψ_0, the length on the sphere is $2\pi R \cos\phi_0$, and on the map it is $2n\pi r_0$, and these are equal.

Whence

$$nr_0 = R\cos\phi_0 = R\sin\psi_0 = 2R\sin\tfrac{1}{2}\psi_0\cos\tfrac{1}{2}\psi_0 \quad (1)$$

From the preceding formula,

$$nr_0^2 = 4R^2\sin^2\tfrac{1}{2}\psi_0 \quad \ldots\ldots\ldots\ldots\ldots \quad (2)$$

Divide (2) by (1):

$$r_0 = 2R\sin\tfrac{1}{2}\psi_0/\cos\tfrac{1}{2}\psi_0 = 2R\tan\tfrac{1}{2}\psi_0.$$

Substitute the value of r_0 in (1); then $n = \cos^2\frac{1}{2}\psi_0$. Substitute for n in the general formula above; then

$$r = 2R\sec\tfrac{1}{2}\psi_0\sin\tfrac{1}{2}\psi.$$

This gives the radii of the parallels. To construct the graticule draw the standard parallel, divide it true to scale and join its centre with the points of division, and construct the other parallels from the formula above. Clearly, in this projection the pole and the vertex of the projection coincide.

Lambert's Projection.—The most important of the modified conical projections, however, is the orthomorphic with two standard parallels, **Lambert's Second Projection, Lambert's Con-**

formal Conic Projection, or simply **Lambert's Projection.** It is sometimes employed in atlas maps, and it is used by the French for their State maps. On it were constructed the later maps of the Western Theatre of War used by the Allies.

Polyconic Projection. — In the **Polyconic** projections each parallel is drawn as if it were the standard parallel on a simple conical projection with one standard parallel. As central meridian a straight line is drawn, and this is divided truly. The parallels are drawn through the points of division, and also divided truly. The other meridians are drawn as smooth curves passing through the points of division of the parallels. The parallels, not being concentric, diverge, and in consequence the scale along the meridians other than the central is exaggerated. The meridians and parallels do not cross at right angles, and so the map is neither equal area not orthomorphic. This projection was developed by the U.S.A. State Survey, and is used by them, France, and this country for topographic maps. It is not suited for atlas maps. In the great international map of the world, to be produced by general co-operation among the civilized nations, a slight modification of this projection is used. Another modification is used by the War Office, in which the meridians cut all the parallels at right angles, and only one parallel is divided true to scale. This is the Rectangular Polyconic.

Bonne's Projection is not truly a conical projection, but it is based on the same general principle. The student should draw it for himself. The central meridian and the parallels are constructed in the same way as in the simple conical with one standard parallel. Then each parallel is divided true to scale, and the meridians are smooth curves joining the points of division, and passing through the poles. The projection is equal area. A very small area bounded by meridians and parallels on the earth is shown in fig. 36*a*, ABCD. The same area on the map is *a*BC*d*. Since the scale is true on the parallels, and since the parallels are at their true distances apart, these stand on the same base and between the same parallels, and are, therefore, equal in area. Since the meridians and parallels do not cross at right angles, the projection cannot be orthomorphic. Obviously, the scale along all meridians but the central is too large. This projection was used for the old State maps of France, and hence is sometimes called the *projection du dépot de la guerre*. It is also used for the Ordnance Survey maps of Scotland and Ireland on scales of 1/63,360 and less, and in the State maps of numerous

European countries. It is very common in atlas maps. One great disadvantage in topographic maps is the fact that the meridians are curved, and hence bearings are the harder to measure. It is useless for atlas maps of large areas, because the inclination between the meridians and parallels becomes very acute far from the central meridian. The student ought to construct for himself Bonne's projection for the case of the equator as standard parallel. In it, of course, the parallels become straight lines (circles of infinite radius). It is called the **Sanson-Flamsteed Projection.** Of course it is equal area. It is frequently used in atlas maps for areas extending about equal distances on either side of the equator, as for Africa. It is also often used in atlases for maps of Australia and Oceania, and sometimes for South America. It makes a serviceable map of Africa as a whole. South America does not extend far enough to the north of the equator to justify its use, and in the other cases the extent in longitude is sufficient to make the marginal angles between meridian and parallel too acute, and the use of the projection is objectionable.

Homolographic Projection.—A very useful projection for the same purpose is the **Mollweide's Homolographic Projection.** This is not a conical projection, but it is best considered at this point. To construct this projection in its commonest form, a circle is drawn to scale so that its diameter shall represent the semicircular meridian. See Appendix, Chapter III, q. 12, and figure. The horizontal diameter of this circle is the equator, and it is produced half its length either way. The vertical diameter represents the central meridian, and its extremities the poles. The equator is divided true to scale, i.e. into the same number of equal parts as there are meridians to be drawn on the map, and the meridians are drawn as ellipses passing through the points of division and the poles. It can be proved that the gores between these ellipses are of equal area. The parallels are straight lines parallel to the equator, and at such a distance apart that the equal area property is conserved. Compared with the Sanson-Flamsteed projection, this one shows less congestion of the meridians near the poles, but the length of the meridians, and their inclination to the parallels close to the margins of a world-map, are even more exaggerated. As a rule, the Mollweide is preferred to the other, but both are useful where equal areas are important, and shapes are of less consequence, in world-maps as in climate charts and distribution maps.

ZENITHAL PROJECTIONS

Imagine a plane touching the sphere at one of the poles. This is realized when the sphere rests on a table as in fig. 47. The planes of the meridians will cut the tangent plane in straight lines, as in SP, and these straight lines in the zenithal projections represent the meridians. To construct a zenithal projection for a map of, say, the north polar regions, therefore, we draw straight lines radiating from the point on the map which is to represent the pole. These are the meri-

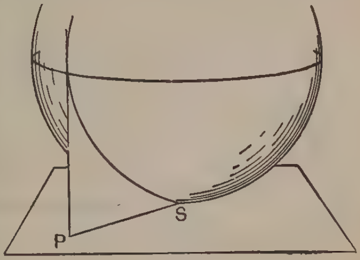


Fig. 47

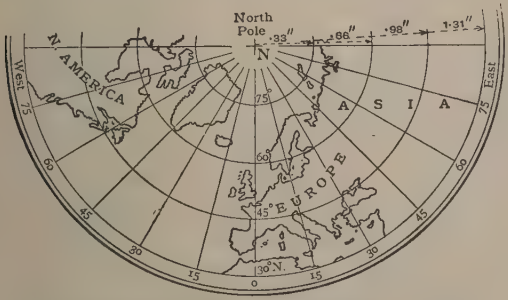


Fig. 48.—Map of Part of Northern Hemisphere on Zenithal Equidistant Projection

dians. In fig. 48 meridians are drawn every 15 degrees of longitude. Clearly, every point on the map lies south of the north pole, which is the centre of the map, and it may be recalled that zenithal pro-

jections show bearings from the centre of the map correct.

The parallels are circles with centres at N. In the zenithal equidistant projection the radius of the parallel of P, latitude ϕ (fig. 49), is the length of the arc NP, the co-latitude ψ of P. In this projection, therefore, the scale along the meridians is correct. In the orthographic projection the parallels are of true radii, and hence of true length. Thus if fig. 49 represents a meridian section of the globe and the tangent plane, in the *orthographic* projection the radius of the parallel passing through P is LP or Np', of length R cos ϕ. This is clearly less than the curved distance NP, the radius of the same parallel in the equidistant projection. Hence in the latter the scale along the parallel is too great, and areas are too great, while in the former the scale along the meridians is too small, and areas are shown too small. Neither of these projections, therefore, is equivalent or orthomorphic.

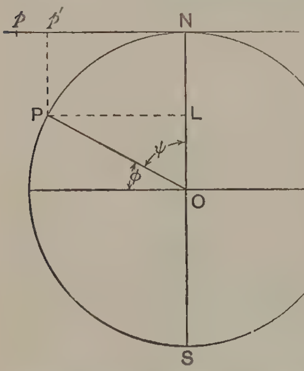


Fig. 49.—Meridian Section of Globe, NPS, and plane, Np, tangent at N

Np = arc NP = $R\psi$ = radius of parallel of P on Zenithal Equidistant Projection. Np' = LP = R cos ϕ = radius of parallel of P on Orthographic Projection.

But the parallels may be chosen so as to make the map either equal area or orthomorphic. In order to obtain an equal area projection, we must recall the fact that the area enclosed between a given parallel

on the globe and the pole is $4\pi R^2 \sin^2 \frac{1}{2}\psi$. This area must be the same on the map and on the globe. If the radius of the parallel on the map is r, then the

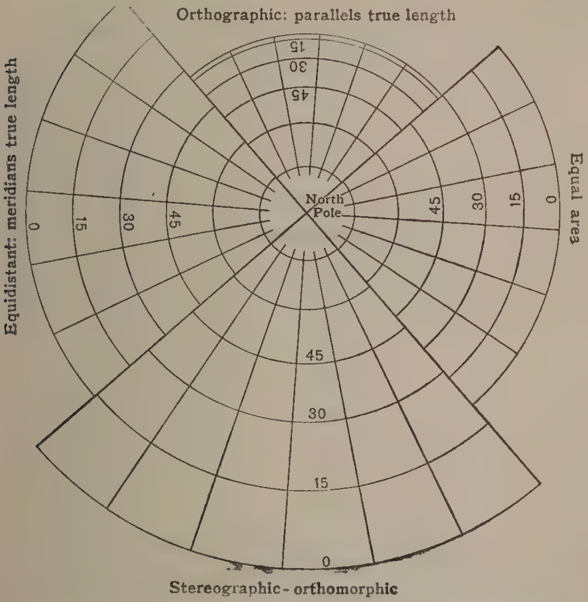


Fig. 50.—Polar Hemisphere in four quarters on four different Zenithal Projections for comparison

Scale, 1 : 250,000,000. Meridians and parallels at 15 degrees interval.

area it encloses is $2\pi r^2$. Equating the two expressions, we arrive at the formula,

$$r = 2R \sin \tfrac{1}{2}\psi,$$

from which the values of r corresponding to the parallels to be drawn may be calculated. Fig. 50 shows this projection compared with three others, and it appears that the radii of the parallels are

greater than in the orthographic, and that hence the scale along the parallels is too great, while since the radii are shorter than in the equidistant, the scale along the meridians is too small.

The orthomorphic projection is also called the

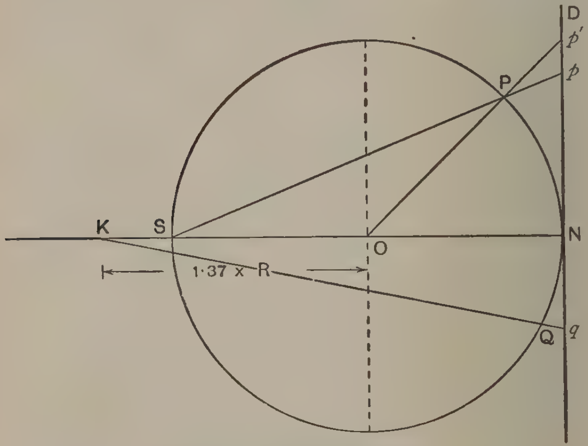


Fig. 51.—Perspective Projections

The circle is a meridian section of the earth; ND is a section of the plane on which the map is made. In the Gnomonic Projection, p' is the position on the map of the point P on the earth; in the Stereographic, the position of P on the map is p. In Sir Henry James's Projection, q is the position on the map of the point Q on the earth, and OK = 1.37 times ON. (If N is the north pole, angle NOP is the co-latitude, ψ, of P, and angle NSP is half the co-latitude. Then the parallels of P on the projections are circles of radii:

In the Gnomonic, $Np' = R \tan \psi$,
In the Stereographic, $Np = 2R \tan \frac{1}{2}\psi$.)

stereographic. The method of finding the radii of the parallels is shown in fig. 51. S is the antipodes of N, the centre of the map. To get the radius of the parallel of P, we join SP, and produce it to meet Np, representing the plane of projection, in p. Np is the required radius. From the right-angled triangle NSp, it is clear that $Np = 2R \tan \frac{1}{2}\psi$, and

the radii of the parallels may be calculated from this formula. Since Np is greater than LP (fig. 49), it is clear that the scale is too great along the parallels; and since the projection is orthomorphic, it follows that it is equally too great along the meridians (cp. fig. 50). If the student has the necessary knowledge of mathematics, he will easily prove for himself that the projection is orthomorphic; if he has not, it would be useless to give the proof here, and so we leave the matter.

Perspective Projections.—A group of zenithal projections is based on the principle exemplified in the method we have used to determine the radius of the parallels of the stereographic projection. If the eye were placed at S in fig. 51, its line of sight through P would cut the tangent plane at p. In these perspective projections the eye is imagined to be placed at some point on the diameter of the globe passing through the point of contact of the tangent plane, and consequently at right angles to that plane, and the position of any point on the map is the point in which the line of sight through the point on the globe cuts the tangent plane. In the Gnomonic (or Central) projection the point of view is the centre of the globe. The radius of the parallel of P (fig. 51) in this projection is, therefore, Np' (and $Np' = R \tan\psi$). The student will readily see that in this projection the scale is too great on both meridians and parallels, whence the projection is neither equivalent nor conformal, and that the map can only be constructed to show less than a hemisphere. Its most important property is the fact that on it great circles are represented by straight lines, and so can readily be drawn on the map. This is because the lines of sight to all points on the same great circle lie wholly in the plane

of that great circle, the point of view being at the centre. When great circle sailing came into general use, it was thought that the gnomonic would oust the Mercator map in navigation, and gnomonic charts were produced in the United States. But, as we shall see later (Chapter VI), while the gnomonic projection is used in the preparation of charts, the charts are published and used on Mercator's projection.

Clarke's Projection is a perspective projection in which the point of view is situated on the diameter at right angles to the plane of projection, and at such a distance from the centre that the total distortion (of length, shape, and scale) shall be as small as possible. Sometimes a special case of this projection, called **James's Projection**, is used in atlases to show the land surface of the globe, but otherwise the projection is not much used. In this case the point of view is situated on a diameter of the equator, and distant from the centre 1·37 times the radius of the sphere (see fig. 51). Another projection, which is zenithal but not perspective, in which the "total misrepresentation" is made as small as possible, is **Airy's Projection** by balance of error. On this projection is constructed the Ordnance Survey map of the United Kingdom on the scale of 10 in. to a mile. The mathematics of these interesting projections is beyond the scope of this book.

Examination of fig. 50 will show that for a map covering a whole hemisphere the various zenithal projections differ a good deal towards the margins, but that in the central part they are much more alike. Thus the errors are less important in the centre of the map, and the less the extent of the map the less the errors. The zenithal projections are, therefore, suited to the representation of compact areas, such as are approximately enclosed in a circle. Asia, for instance, is compact, and for a map of it the zenithal projections are suited. Its great extent in latitude makes the conical projections less suitable. But in order to have the full benefit of the zenithal projection in constructing a map of Asia, it is clear that the centre of the projection should be the centre of the area shown on the map. In other words, the tangent plane should touch the globe, not at the pole, but at a point about lat. 40° N., long. 90° E. Such a tangent plane is

said to be oblique, or sometimes horizontal. A plane tangent at the pole gives a polar projection; a plane tangent at a point on the equator gives an equatorial projection; a plane tangent at some other point gives a horizontal projection. In a horizontal projection the meridians do not become straight lines radiating from a point, and the projection is harder to construct. One can, however, imagine a set of great circles passing through the point of contact of the plane and through its antipodes, which would appear on the map as straight lines. The meridians and parallels are constructed by calculating the points in which they cross these radiating straight lines, and, of course, they alone appear on the finished graticule. For maps of Asia most atlases employ the zenithal equal area or equidistant. The student will, therefore, be able to verify the fact that the meridians and parallels are curved lines. Many atlases also employ Bonne's projection for the same map: for instance, in Bartholomew's *Advanced Atlas* the main map of the Continent is on the zenithal equal area, while smaller maps of Asia as a whole are on Bonne's projection. Both maps are equal area, but examination of the marginal parts will show that the meridians and parallels are more nearly at right angles, and that the lengthening of the meridians is much less, in the zenithal projection, so that in this case it has the advantage of distorting shapes much less than the other.

Cassini's Projection.—This, the last projection we shall refer to, is entirely a conventional projection, and it owes its importance to the fact that it was developed by the French mathematician Cassini III for his great map of France, one of the earliest and best known of modern maps. It was employed widely on the Continent, as well as for the Ordnance Survey maps of this country on scales of 6 in. to the mile and greater, and for all maps of England, except the 10 mile to the inch.

Cassini carried out a survey of France based on the measurement of a principal meridian and of certain lines perpendicular to that meridian. Parallels are at right angles to meridians *where they intersect*, on the surface of the earth, but not elsewhere; the perpendiculars measured by Cassini were great circles. He constructed his projection by drawing a straight line to represent the principal meridian, and straight lines at right angles to this to represent his perpendiculars. On the map the principal meridian and a chosen perpendicular provided what in geometry are called rectangular axes. Fig. 52 shows the principle of this projection: *a* shows the globe, *b* the map. The lettering is the same

on both. ON is the principal meridian, OE a great circle perpendicular to ON, and cutting the meridian in O, the origin, which should be about the centre of the map. P is any point on the region to be mapped, and PM is the great circle passing through P, and at right angles to the principal meridian, ON. The figures show how the point P is plotted on the map by the rectangular

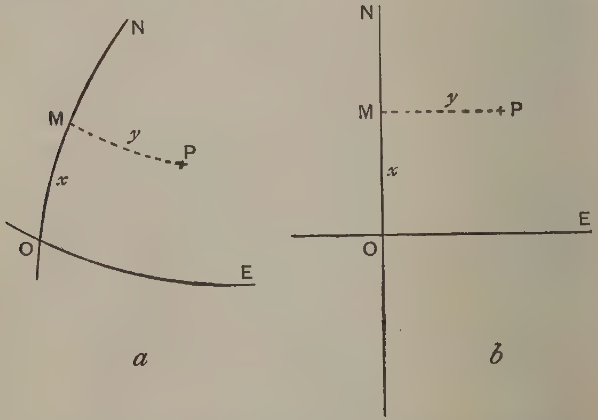


Fig. 52.—Cassini's Projection

Fig. *a* refers to the globe; *b* to the map. O is the centre of map, ON the meridian of O. PM is a great circle through P at right angles to ON. OE is a great circle through O at right angles to ON.

co-ordinates x, y. Sometimes this is called projection by rectangular co-ordinates.

The rectangular co-ordinates of the intersections of all the meridians and parallels to be drawn as the graticule are calculated in this way, and the points plotted on the map. The graticule is completed by drawing smooth curves through these points. The meridians are not straight lines, but if the map does not extend far on either side of the principal meridian, the curvature is not very great. The parallels, which also are curves on the map, are not at right angles to the meridians, and consequently scales, which are true along the principal meridian and at right angles to it, are not true elsewhere. For a country extending about 150 miles on either side of the central meridian, however, these defects are very small.

For the question of the use and importance of projections, the student is referred to the chapter on the interpretation of maps (Chapter V).

CHAPTER IV

THE MAKING OF MAPS—II

Chain Surveying. — The next operation in the making of maps is the measurement of the ground with the necessary speed and accuracy. Several methods are employed, and the simplest is that of chain survey. Till recently this was done with Gunter's chain. This was 66 ft. long, and consisted of 100 links, each a piece of stout iron wire bent into an eye at either end. At each end of the chain, and swivelled to it to avoid twisting, was a handle, the outer side of which was flat, and the length of the chain was the distance between these flat sides, which could be used as straight-edges for ruling lines to mark the ends of chain-lengths. A serious objection to the chain for accurate work is that each joint is a wearing surface, and gradually the chain becomes decidedly too long in use. The links are, therefore, replaced in modern work by a steel band or tape, the swivels and handles remaining. The size of the band varies, but it is often about the weight and appearance of clock-spring. The term "chain" is used alongside those of "tape" and "band", and the units remain the same, the chain of 66 ft. or 22 yd., on account of its convenience in land work, one square chain being $\frac{1}{10}$ of an acre, and the link of 0·66 ft., or nearly 8 in. In general and scientific work, however, it is customary to employ tapes of 100–300 ft., divided to feet and tenths, and of 30–100 m.; and steel wires,

which are lighter and less liable to "kink" and break than tapes, are coming into use, and are preferred by workers in the colonies and new lands.

To mark the ends of tape-lengths on the ground, "arrows" are employed. These are made of stout steel wire, pointed at one end, bent into a ring at the other, and a foot or so long. To the ring is attached a piece of rag to render the arrow more easily seen when stuck in the ground.

The work requires two men, one at either end of the tape. First, the line to be measured must be set out on the ground. A mark, such as a picket, is fixed at each end of it. If one of these cannot be seen from the other, or if one or other is not visible from every point on the line, more must be placed, all in line, so that the alignment may be maintained in the work. In the actual measurement one of the men takes ten arrows and one end of the tape, and proceeds along the line, pulling out the tape as he goes. When the tape is all out, the man left behind at the beginning of the line calls "Chain", and the other stops, faces about, and takes up the position of "attention", heels together. The first duty of the rear man is to see that the forward one is directly in the line. Standing over the initial mark, he motions him to his own right or left by waves of the right or left hand. The forward man moves slowly, as directed, right across the lie of the tape, bringing his heels together after each pace. When the rear chain-man sees the forward mark right in line with the heels of the other, he throws up an arm to signal that the alignment is completed. Good surveyors permit no slovenly observance of this and other parts of chain discipline. The rear man now holds the flat end of his handle over the mark at the beginning of the line, the forward one, without shifting his

footing, pulls the tape taut, and fixes an arrow in the ground just ahead of his handle, canted a little forward, and with the ring at right angles to the tape. He also shakes out any curves or bends in the tape by an up-and-down movement of his hand. He puts on the regular strain, and adjusts the head of the arrow to the end of the tape. This is done without touching the arrow, but by pressing with the foot on the ground ahead of it so as to bring it more upright. This arrow must not be touched now until completely finished with. The adjustment complete, the forward man calls "Right", and the rear man, if satisfied, drops his handle; if not, he calls "Repeat", and the work is checked over, and, if necessary, amended. This finished, the rear man drops the tape, and the forward one pulls it out again until warned by "Chain" from the other that the rear end is at the arrow. The steps are then gone through again until the line is completed, the rear man picking up and carrying on the arrows as he passes them. The number of arrows he has is the number of chain-lengths measured. With those still in the possession of the forward man there should be ten in all, and it is important to make sure of this, because nothing is easier than to "drop a chain-length". Should an odd fraction of a chain-length remain, this is measured to the nearest 0·1 ft. and entered. If the lines are more than 10 chain-lengths, it is usual to have eleven arrows, two carrying, say, red rags, the rest white. Ten, including one red arrow, are given to the forward man, and the red arrow he plants last. When he has exhausted his arrows, 10 chain-lengths are entered in the field-book, and the rear man hands on ten arrows, including the odd red one, to the forward one. The red one in the ground now becomes the odd one.

So far we have only learned to chain a line on the flat. Suppose it is required to survey the bank of a river, as that shown in fig. 53. A straight line, AB, is set out as close to it as possible, and as long as convenient. At A the distance to the river-bank is measured along the line at right angles to AB.

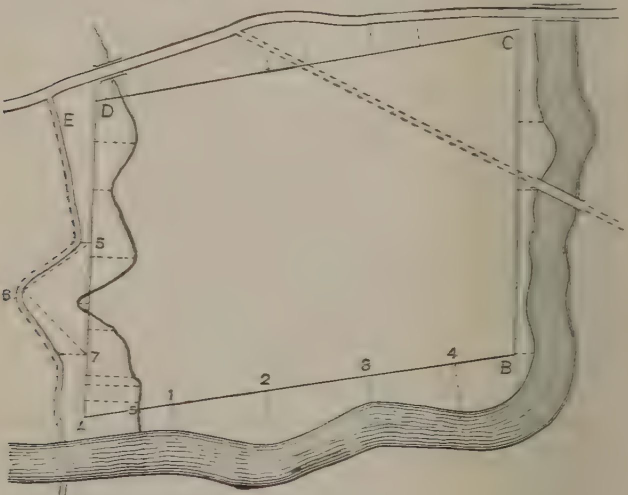


Fig. 53

Opposite the point 1 the river takes its first bend. Suppose this occurs about the middle of a chain-length. After the forward arrow has been fixed, the chain is left in position on the ground. The surveyor walks up till the line between his position and the bend on the river is at right angles to AB. This may be judged by eye if the perpendicular is very short. If it is longer, it must be set out by instrument, such as the optical square or cross-staff, or a set-square will do at a pinch. This perpendicular distance is then

measured with a short tape; a good linen tape is often used. This measurement is called an *offset*, and since it is measured to the right of AB, in the direction in which the work goes on, it is a right offset. The distance of the point 1 from A is now read from the tape as it lies, and entered with the offset as explained below. Offsets are made similarly at 2, 3, . . ., and noted together with the distances of these points *from A*. AB also crosses a brook, and the distance of the crossing from A, together with offsets to the brook, are measured (5).

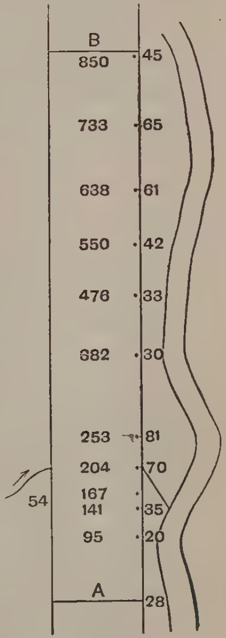


Fig. 54

Field-book.—The observations are entered in the *field-book* immediately they are made. The book used is ruled as in fig. 54. The central column represents the line AB. In it are entered the distances measured along the line. In the margins to right and left is made a sketch of the features surveyed, as indicated in the figure, and the offsets are entered in their proper places and in the proper side. The entries begin at the foot of the page, and they are spaced roughly to scale. For this purpose it is very useful to use a book ruled in $\frac{1}{10}$-in. squares—a "sectional book".

Offsets should always be as short as possible. Those in the figure could have been considerably shorter but for the need to keep the diagrams clear.

Long offsets mean slower work and the likelihood of error. Whenever a long offset is unavoidable, or when a particularly important point is to be fixed, the method used in line DA to fix the point 6 should be adopted. Instead of measuring a single offset, the distances from two points on the line to the required point are measured; and, as in the figure, these may well be points from which offsets are required. The student ought to compile pages of the field-book for BC, CD, DA by measuring from the figure, and then he ought to select a suitable area and survey it in the field.

Plotting a Survey.—The next question is the plotting of the measurements. We must begin by laying down the lines measured, AB, BC, . . . Here a difficulty at once arises. Having drawn AB, how are we to put BC in its right position? Clearly the information is not sufficient. But if AB and BC can be drawn, it is easy to get in the other lines. The difficulty is solved in this work by measuring one of the diagonals of the quadrilateral. AC is the longer, but it will enable additional information respecting the brook and a path to be got, and avoid some long offsets. We have divided the work into triangles, because the lengths of three sides of a triangle completely determine the triangle; that is, they enable us to draw it to a scale. As a matter of fact, all survey is built up on triangles. The two triangles having been drawn, the plotting of offsets is a simple matter, and the detail can be sketched in from the points so fixed. Let the student now plot from his field-book on the scale of 1 : 5000. For this purpose he will require a scale: boxwood scales, divided to show feet or other units on various scales, can be purchased, and are usually employed in such work. He may draw a

scale for himself by the methods indicated in the examples.

1. Construct a scale of yards on R.F. 1 : 4000. 1 in. on the scale will represent 4000 in. on the ground, and 3 in., a convenient length for the scale, 12,000 in., or nearly 333 yd. To have a length convenient to subdivide, let the scale represent 300 yd.: it will then be (300 ÷ 4000) yd., or 2·7 in. long. A line of this length is to be

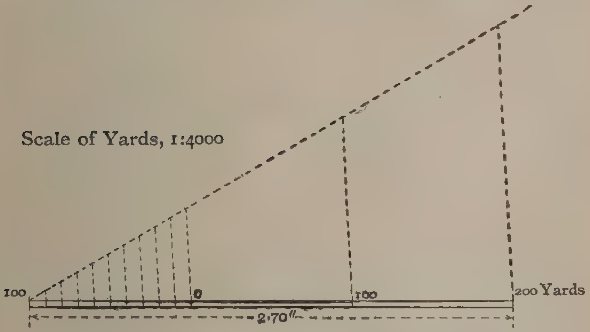


Fig. 55.– Dotted lines indicate construction lines to be erased finally. Note that the angle at which the first construction line is drawn is about 30 degrees, and the lengths laid off along it are such that the lines transferring the divisions to the scale are nearly at right angles to the latter. This makes for accuracy of work, and no scale should be accepted as satisfactory unless the divisions have been tested and found to be equal.

drawn, divided by the ordinary method into three equal parts, of which that to the left is further divided into ten, and the scale completed as in fig. 55.

2. Construct a scale to show metres on the scale of 1/10,000. A length of 10 cm. (rather over 3 in.) will represent 100,000 cm., or 1000 m.

We cannot expect to measure all lines on flat ground, but what a map shows is the horizontal distance between two places, not necessarily the distance along the ground. Thus, if there is a slope up from A to K, as in fig. 61, the distance on the map is not AK, but

AK′, where K′ is vertically under K. We must reduce the measured distances to horizontal distances. Clearly, if the angle of slope is α, the distance required, AK′, can be derived from the formula $AK' = AK \cos \alpha$. This is called *reducing for slope*; in chain survey it is only necessary if the angle of slope exceeds 5 degrees. Some surveyors prefer to avoid it by chaining in short lengths, holding the tape horizontal, and fixing the ground-mark under a plumb-bob held at the end of it.

Chain survey is all very well for small areas. When we come to the mapping of large countries we meet difficulties, and these are bound up with the question of the accuracy attainable. A fair surveyor will chain a line correct to 1 in 1000 at least. What exactly does this mean? There is usually no time to chain the same line twice, unless a large error in the first measurement is shrewdly suspected. But suppose the same line is chained four times, and the results are as set out in the table below.

	Distance as Measured.	Difference from Mean.
No. 1	5983·4 ft.	0·8 ft.
,, 2	86·8 ,,	2·6 ,,
,, 3	80·1 ,,	4·1 ,,
,, 4	86·6 ,,	2·4 ,,
Mean.	5984·2 ft.	2·5 ft.

The four measurements differ among themselves. Taking the mean of them as standard, we find that No. 3 differs from it by 4·1 ft., the others by less amounts, while the greatest difference between actual measurements is 6·5 ft., between Nos. 3 and 4. We

cannot say what is the correct distance, or whether there is one; it is likely that the average is more exact than any individual measurement, but there is uncertainty to the extent of some 6 ft. Any single measurement may be expected to be wrong by not more than 6 ft. in some 6000 ft., or 1 yd. in 1000 yd., or 10 yd. in 10,000 yd. This shows the method of testing the accuracy of work, and of forming an opinion of its reliability.

Now, in surveying for a map we can take it that the errors of the survey should be smaller than can be shown on the map. A skilled draughtsman might do better; but let us take it that the closest we can measure lengths on paper is 0·01 in. On the scale of 1 in. to the mile, this represents a hundredth of 1760 yd., or just over 17 yd. Therefore if the *total* error of measurement is under 17 yd., the work is good enough. On the 6-in. scale the permissible error is under 3 yd., and less for greater scales. One sheet of an Ordnance Survey 1-in. map may be 20 in. broad, and so may represent a tract of country 20 miles wide. If surveyed by chain, it will not be done on one line only, but still each line may contribute error at the rate of $1\frac{3}{4}$ yd. to the mile, which would give a total error of 35 yd., represented by $\frac{1}{50}$ in. On the 6-in. scale the error would amount to more than $\frac{1}{10}$ in. on the map. Suppose we are working on the scale of 6 in. to the mile. We are allowed an error of 3 yd., and this may occur in chaining a line 3000 yd. long. Hence it is not permissible to depend on chain survey for longer lines, and more accurate methods must be found. The method employed in the survey of a large area, such as the United Kingdom, is to have all over the country a large number of points, no two of which are more than 3000 yd. apart, and the positions of

which have been determined more accurately than can be done by chain survey. Examination of a 6-in. map will show here and there dots surrounded by minute triangles. These indicate such points, and they are usually less than a mile apart, because the country has been surveyed for maps of scale larger than the 6-in.

Triangulation.—Surveying, it has been said, depends on triangles, and the accurate method employed for the fixation of these points forming the framework of the survey of the country is called Triangulation. The detail between the points may be mapped by chain survey along lines running between, or based upon, these trigonometrical stations or "trig. points".

Geometry teaches that a triangle is completely determined—

1. If the lengths of the sides are known, which is taken advantage of in chain survey.
2. If the lengths of two sides and the angle between them are known, which is the basis of the method called Traverse.
3. If the length of one side and the size of two of the angles are known. Triangulation depends on this. In the plane triangle the sum of the three angles is 180 degrees; hence if two of the angles are known, the third is easy to deduce; but if the three angles are measured, their sum is a check on the accuracy of the measurements. In triangulation the three angles are always measured. Small triangles on the surface of the earth can be treated as plane triangles; though they are really spherical, if their sides are no more than 3 miles long, the difference from plane is not appreciable.

Suppose A and B (fig. 56) are two points, and that we find the latitude and longitude of A, the bearing of AB by the methods of Chapter II, and the length of AB by measuring. Let C be a third point. Take a theodolite, and set it up at A, B, C successively, and measure the angles of the triangle ABC. From the information available we can now plot A on the map, draw AB, complete the triangle ABC, and so put B and C on the map. Or we can calculate by trigonometry from the triangle the lengths of its sides, find the bearings of BC, CA from that of AB and the angles, and thence calculate the latitude and longitude of B, C (see also Chapter IX, pp. 261, 2). If, now, D be a fourth point, since we know the lengths of BC, CA, if we measure the angles of the triangles, we can similarly calculate the position of D from the triangles BCD, BAD. The two independent results will indicate the accuracy we are attaining. This can be extended to any number of other points, and it is the principle of triangulation.

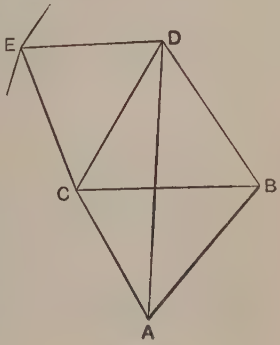


Fig. 56

The accuracy of this work depends on, first, the care with which AB is measured, second, the care with which the angles are measured. Angles may be rapidly and accurately measured by means of the theodolite. It is a much harder business to measure a distance on the earth, and it takes more time to do it accurately. The ease and accuracy of the measurement depend on the kind of country on which the

distance is measured. The great advantage of triangulation is the fact that it is only necessary to measure one such distance, called the *base*, and it can be done on the most suitable part of the area to be surveyed. If more than one base can be measured at considerable distances from each other, the measured length can be compared with the same distance as calculated through the triangulation, and so valuable checks on the work can be obtained.

The shape of the triangles and the size of the angles have an important bearing on the precision which can

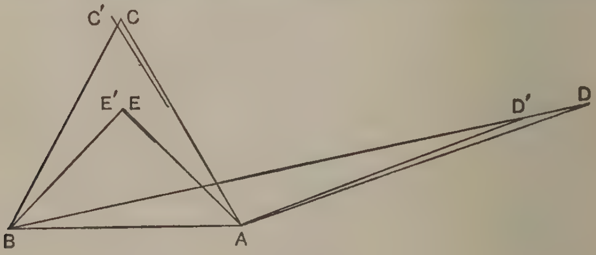


Fig. 57

be expected in the work. In fig. 57 C, D are two points fixed from A and B. The angle CAB is 60 degrees, the angle DBA 10 degrees, and the measurements are such that they may be 1 degree in error.[1] Suppose they are each 1 degree too small, and to correct this they are enlarged by that amount. The points are moved to C′ and D′, and the change in position of D is about five times as much as in that of BC. The angle EAB is 45 degrees, and if it be altered 1 degree the change in the position of E is even less than that of C. Thus an error in the measure-

[1] The greatest error allowed in triangulation is only a few seconds, 60 at most; we choose such a large error as 1 degree so as to be able to show it in the diagram.

ment of an angle does much more mischief if the angle is small than if it is large. The best way in which to fix the position of a point is to have it at the apex of an isosceles right-angled triangle; but each of the three points of a triangle cannot be so situated, and

Fig. 58.—Triangulation of England, extreme south-western corner

the best compromise is to have the triangle as nearly equilateral as possible.

Carrying out a triangulation involves selection of the trigonometrical stations, and of the base or bases, measurement of the base and of the angles. The work on the bases and on the angles can be done at the same time by two or more parties.

Each trig. point must be visible from the others in its neighbourhood in order that angles may be able

to be observed to it from them. Thus trigs. are usually placed on the tops of hills and other conspicuous places, and in flat country it is often very difficult to obtain satisfactory sites for them. There are two marks required on the ground at each trigonometrical point. One is a permanent mark, by

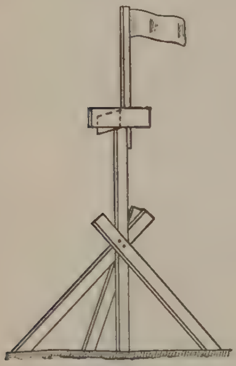


Fig. 59.—Signal commonly erected by Ordnance Survey. The pole stands vertically on the buried mark. It must be removed temporarily to allow the theodolite to be set up.

Fig. 60.—Quadripod Beacon. The upper part of the pyramid is covered with white calico, the apex being vertically over the buried mark. A theodolite may be set up under this signal.

means of which the station may be found with certainty and precision if the temporary surface-mark is moved or lost during the progress of the work, or if the station is required for revision of further survey at a later date. Such marks are now, as a rule, a brass plug sunk flush into a block of concrete or stone, and buried a foot or more underground. The actual mark is a fine cross engraved on the polished surface of the plug. The mark has to be protected by a cap before the earth is thrown on it. The second kind of mark is a "beacon", or signal, a temporary erection, which

can be seen from a distance. It may be a pole with a flag or vane to render it easier to pick up, the pole being fixed quite vertical and centred over the buried mark, or it may be a larger erection; but whatever it is it must have a narrow part, which is very carefully placed so as to be exactly over the permanent mark. In flat country, especially if it is wooded, or the view otherwise obstructed, church towers may be used for the sites of trigs.; but in new country these do not exist, and special erections, such as platforms in tall trees, or even high towers, must be made, both for taking observations from and for marks to which observations may be made. Convenient places are usually not found so that the triangles may be equilateral, and the best has just to be made of things; if possible, so that no angle shall be less than 20 degrees. The sites are selected and marked, and as soon as this has got well in hand the observation of the angles may begin.

Theodolite.—The instrument used for measuring the angles is the theodolite. Theodolites are of various sizes, modern practical instruments ranging from 4 in. to 12 in., or even 18 in., being named from the diameter of the horizontal plate. The instrument is set up in place of, or, if possible, under, the signal or temporary mark, and, the buried mark having been uncovered, is centred over the cross. If a large instrument capable of great refinement of work is used, it will have to be protected by wind- and sun-screens, because wind and unequal heating make appreciable errors in the work of observing. In this country it is customary to observe in "rounds" of angles. The instrument, after having been levelled, is sighted on one trig., and the plates adjusted so that the horizontal angle is about zero, rather over than under, but never

exactly at zero. This trig. is called the "reference object", or R.O. The reading having been noted, the telescope is swung round on the next to the right or to the left, and the reading taken and booked, and this is continued "round the clock", finishing up on the R.O. The final reading on this will not be exactly the same as the initial reading, but unless it differs from it by a second or two only, according to the size of the instrument, the round is not satisfactory, and must be repeated. Both verniers are read each time as a check on the reading. If when using the telescope of the instrument the observer has the vertical plate on his right, the instrument is said to be "face right", or F.R. His next step must be to take a round face left. To do this the telescope is turned half round on the horizontal axis and the instrument on the vertical, so as to bring the R.O. into the field of the telescope with the scale again near zero, but not necessarily at the same reading as before. The round is taken as before. The object of repetition is this. The vertical axis of the instrument is not likely to be just exactly in the centre of the horizontal plate. If it is not, the F.R. angles will perhaps be too small, but then the F.L. angles will be just as much too large, and the mean of the two will cut out the error. This, however, is still not enough. The graduations of the scale are never absolutely even right round, and to meet this it is customary to measure each angle on several parts of the scale. Another F.L. round is taken with the zero about, say, 60 degrees, and then repeated F.R. This second set of readings is said to be taken on the second arc. The number of arcs taken depends on the accuracy required. For rough work these two may be sufficient, but for careful work four, eight, or even more will be taken. The observa-

tions completed at a station, the instrument is removed, the signal replaced and carefully plumbed.

Measurement of a Base Line.—The next question is the measurement of the base. This is chosen on a flat, even place. Formerly bases were 5 miles or more long; now it is found that shorter bases, say a mile or so, are not less satisfactory; but, of course, the length of the base will depend on the size of the survey and the length of the sides of the triangles. The site having been selected, the ends of the base are marked in the same way as trig. points, and stakes or other marks are placed at regular intervals along its course, great care being taken to have them exactly in line. Rough bases may be measured in the same way as lines are chained, only the measurements are made twice, or more. For more accurate work there are driven into the ground at intervals of one tape-length stout pickets, on top of which are nailed pieces of board covered with sheet zinc. The tape is used at constant tension, spring balances being attached to the handles for the purpose, and the tape ends are marked by ruling with a knife fine lines on the zinc, the straight-edge being the ends of the handles. No attempt is made to bring the ends of the tape directly over these fine lines as in chain survey they are brought over the tops of the arrows; but the distance between the ruled lines on each piece of zinc is measured separately with a fine scale, and added to, or subtracted from, the tape measurements according as they come. More exact methods still are used on important surveys.

Certain corrections to the measured length must be made. The first is that for slope referred to above in reference to chain survey. In order to apply this the base is very carefully levelled. Secondly, the length of

the tapes depends on temperature. They are made to be correct at a given temperature. At higher temper-

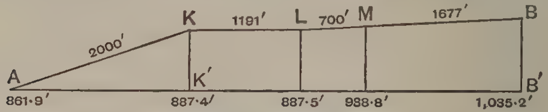


Fig. 61.—Correction for Slope. Slopes of Ground on which was measured the base AB

Figures above, lengths of AK, KL . . .; figures below, heights above sea-level of A, K, L . . .; AB′, reduced length of base.

atures they are longer, at lower, shorter. The temperature of the tape is taken at several points of its length each time it is used, and a correction applied. The correction is not required in rough work, but its amount may be gauged by the fact

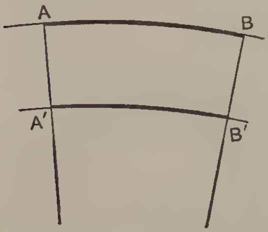


Fig. 62.—Reduction to Sea-level

A base, AB, is measured on a plateau high above sea-level. Its reduced length is A′B′, at sea-level, which is shorter. AA′, BB′ are vertical, i.e. they lie in radii of the earth.

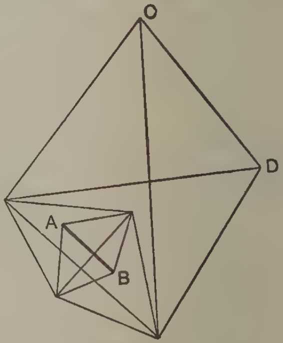


Fig. 63.—Base Extension

A base, AB, measured for a triangulation whose length of side is exemplified by CD. The base was connected to the triangulation by means of the small well-conditioned triangles.

that a base a mile long will measure at 60° F. some 8 in. shorter than if it were measured at 40° F.[1] Still

[1] The *coefficient of linear expansion* of the steel of tapes is taken as 0.00000625 for 1° F., i.e. each foot of the tape becomes 0.00000625 ft. longer if warmed 1° F. 5280 ft. will expand 5280 times as much if warmed 1° F., and twenty times as much as that if heated from 40° to 60° F., i.e. through 20° F.

another correction is for height above sea-level. This correction is small, and only applicable to very exact work. A base of a mile, measured at a mean altitude of 800 ft. above sea-level, must be reduced by rather less than 3 in., which is not too small to matter in very important refined work. Fig. 62 gives the reason for this reduction.

Usually the base is much shorter than the sides of the triangles; the latter may be 20 to 100 miles long, and if the base, 1 mile long, were in the same triangle as one of these, the shape of the triangle would be very bad. Badly shaped or "conditioned" triangles may be permissible when necessary, but in connecting up the base the triangles must be good. One method of achieving this is shown in fig. 63. This is called base extension.

We give now a set of observations and measurements to show how the work is put to use.

Example of work on triangulation, no great refinement of accuracy being aimed at.

1. Base: Measured along ground sloping as in fig. 61, in four parts on account of changes of general slope.

(*a*) AK, 2000′: level of A, 861·9′, of K, 887·4′; difference of level, 25·5′.

log 25·5,	1·406 54	log 2000,	3·301 03
log 2000,	3·301 03	L cos 0° 44′,	9·999 96
L sin angle,	8·105 51	log AK′,	3·300 99

Angle of slope, 0° 44′. Horizontal distance, 1999·8′

(*b*) KL, level. Horizontal distance, 1191·0′

(*c*) LM, level of L, 887·5′, of M, 938·8′; diff., 51·3′.

Calculation as under (*a*):

Angle of slope, 4° 12′. Horizontal distance, 698·1′

(*d*) MB, angle of slope, 3° 18′. Horizontal distance, 1674·2′

Length of base AB reduced to horizontal, 5563·1′

2. Specimen page of Angle Book used in the field. Angles observed from Trig. Point *A*.

Station, *T.P. A.* Observer, *Tom Jones.*
Date, 12/7/19. Booker, *D. Brown.*

Weather, *Bright, slight haze.*
Reliability of observations, *Fair.*
Instrument, *4″ transit theodolite.*

Arc.	Station.	Horizontal Angles. Vernier. A.	B.	Mean of A and B.	Final Mean.
F.R.	*T.P. F, R.O.*	*00° 39′ 46″*	*39′ 56″*	*00° 39′ 51″*	*00° 39′ 57″*
Sw. R.	,, *C*	*21 04 23*	*04 16*	*21 04 20*	*20 24 23*
	,, *B*	*83 29 03*	*28 55*	*83 28 59*	*82 49 02*
	,, *G*	*147 16 20*	*16 13*	*147 16 17*	*146 36 20*
	,, *E*	*229 31 42*	*31 40*	*229 31 41*	*228 51 44*
	,, *F, R.O.*	*00 40 08*	*39 58*	*00 40 03*	*00 00 00*

NOTES.—1. "Sw. R." in column 1 means that the instrument is turned constantly to the right in taking the round. The F.L. round on the same arc would be swung left. The object is to eliminate the effect of any back-lash.

2. The two verniers or micrometers on the horizontal arc are lettered A and B, those on the vertical C and D.

3. It is not necessary to repeat the number of degrees in column 4.

4. The figure at the top of column 6 is the mean of those at the top and bottom of column 5. The other figures in column 6 are obtained by subtracting this from the corresponding figures in column 5, and therefore represent the angular distances of each signal from the R.O.

5. In taking the means for column 5, ½ seconds are taken as whole seconds. Neglect ½ seconds in the F.L. round.

3. *Solution of Triangles.*—At this station one round F.L. on the same arc, and F.L. and F.R. rounds were made on another arc, zero 90 degrees. The same was done at each of the other trigs. of the survey, and means were taken for each of the angles. These could be plotted by means of a protractor, or by the method of chords (see Chapter VI, pp. 162–3); but doing so would defeat the end in view, the prevention of the accumulation of errors, which individually cannot be plotted, to an amount large

enough to be plotted. The triangles are, therefore, solved trigonometrically as follows. We shall deal with the triangle ABC, the side AB being the base of the triangulation (see fig. 64).

Formula used: $a/\sin A = b/\sin B = c/\sin C$;

whence $a = c. \sin A \div \sin C = \sin A. c. \operatorname{cosec} C$,
and $b = c. \operatorname{cosec} C, \sin B$.

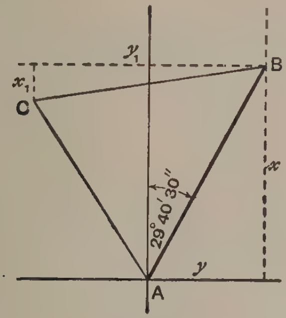


Fig. 64

Computation:

	Angles as Read.				Angles Adjusted.		
A.	*62°*	*24′*	*43″*		*62°*	*24′*	*38″*
C.	*57*	*58*	*19*		*57*	*58*	*14*
B.	*59*	*37*	*13*		*59*	*37*	*08*
Sum ...	*180*	*00*	*15*		*180*	*00*	*00*

L sin A	*9·947 62*	*Sum* = *log* a = *3·764 66*
log AB	*3·745 32*	a (*BC*) = *5816·5′.*
L cosec C	*10·071 72*	
L sin B	*9·935 85*	*Sum* = *log* b = *3·752 89*
		b (*AC*) = *5661·0′.*

NOTE.—The triangle is so small that it can be regarded as plane, and its angles should together come to 180 degrees. They do not, being 15″ in excess, due to unavoidable errors of observation. If the angles are equally reliable, as is assumed, then each may be taken to be 5″ too great, and adjusted accordingly. If the error had been greater, say 1′, the angles might be too doubtful for the work, and it would be necessary to re-observe them.

4. *Rectangular Co-ordinates.*—The points are put upon the map by means of their distances north and east of A, these distances being called *rectangular* co-ordinates. They can be calculated thus:

The bearing of B from A is observed to be 29° 40′ 30″ (see fig. 64). Then the distance of B north, x, and east, y, are calculated:

log AB	*3·745 32*		*3·745 32*
L cos 29° 40′ 30″ ...	*9·938 94*	*L sin 29° 40′ 30″* ...	*9·694 67*
log x...	*3·684 26*	*log* y	*3·439 99*

x = *4833·5′*; y = *2754·2′*.

Bearing of AB ...	*29° 40′ 30″*	*Bearing of BA* ...	*209° 40′ 30″*
Angle A	*62 24 43*	*Angle B*... ...	*59 37 13*
Bearing of AC ...	*327 15 47*	*Bearing of BC* ...	*269 17 43*

NOTES. 1. AB is so short that the convergence of the meridians may be neglected, and the bearings in the two directions can be taken as differing by 180 degrees (cp. Chapter I, p. 11).

2. Since 62 cannot be subtracted from 29, 360 must be added to the latter. 62 must be *subtracted* in the first case, because to bring AB in line with AC it must be turned back through 62 degrees odds, and 59 degrees odds must be added in the second case, because to bring BA into line with BC it must be swung forward, i.e. counter-clockwise. This should be studied out in fig. 64.

Rectangular co-ordinates of C:

log AC	*3·752 89*		*3·752 89*
L cos Bg.	*9·924 82*	*L sin Bg.*	*9·733 02*
	3·677 71		*3·485 91*

x = *4761·1′*; y = *−3061·3′*.

log BC	*3·764 66*		*3·764 66*
L cos Bg.	*8·096 45*	*L sin Bg.*	*9·999 97*
	1·861 11		*3·764 63*

x = *−72·6′* y = *5816·1′*

For B, x = *4833·5*; y = *2754·2*

∴ *For C*, x = *4760·9*; y = *−3061·9*.

NOTES.—If x is north of the origin it is +, if south −.
If y is east of the origin it is +, if west −.

The origin in this case is A. The co-ordinates got from BC are distances south and west of B (see fig. 64), and distances north and west of A must be calculated from the co-ordinates of B. The student will see the need to draw sketch diagrams for every case he works out.

It will be recognized that x and y are the rectangular co-ordinates referred to in Chapter III, p. 94; only, since we are dealing with a comparatively small area on the earth, we can regard it as flat, and think of the meridians and parallels as straight lines at right angles to each other. The co-ordinates are what are called differences of Latitude and Departure in Chapter IX, pp. 251–2, and from that chapter it will be seen how to derive the latitudes and longitudes of B, C, . . . from that of A by means of x and y.

The triangulation which we have been describing, with its assumptions that the earth may be regarded as plane, is not of very great accuracy, and is, therefore, the source of error that piles up gradually, and would eventually become serious enough. Hence it is controlled by systems of triangulation of which the triangles are much larger, the observations made with greater care, and the calculations with as few simplifying assumptions as possible. The triangles are solved as spherical triangles. Primary or geodetic triangulations are of the utmost accuracy obtainable, and the triangles involved may have sides over 100 miles long. Secondary triangulations are of less, but still great, accuracy, while the type of triangulation we have studied is called minor or tertiary triangulation. The higher the accuracy of the work, the more costly it is. Hence finer work is done only for the control of cheaper and cruder operations that suffice for restricted areas of country.

Ordnance Survey.—The Ordnance Survey of this country used the method of chain survey for detailed surveying, but another method has been developed, is used in colonial work, and was employed for the

construction of maps used in the Great War. The plane-table was for a long time a crude instrument, but accurate methods of employing it were developed by the Survey of India.

Plane-table.—The plane-table consists of a drawing-board mounted on a rigid tripod, like a camera-stand with unjointed legs. The board is fixed to the legs by means of a screw, and loosening the screw permits it to be swung round in a horizontal plane, while it may be fixed in any position by tightening the screw. A sheet of drawing-paper several inches larger than the table is mounted on it. This must be done by damping the paper, so that it may stretch, and, drying on the board, remain tight and even. It is fixed by pasting the overlap on the under side of the board. Drawing-pins may be used to keep the paper in place while it is drying, which takes at least a day; but they must not be left in the board in the field, for if they are on the upper side they get in the way, and if they are anywhere at all they interfere with the compass that is used for determining the magnetic meridian. It is best to cover the board with a sheet of linen, also fixed by pasting down an overlap, and to mount the paper on top of this, pasting it on top as well as underneath the table. This is always done in professional work.

Alidade.—With the plane-table is used the **alidade.** It consists of a heavy straight-edge, at either end of which is mounted a hinged sight. The back-sight has a narrow vertical slit in it, the fore a wider slit in which is strung a vertical wire or hair. The line of sight is parallel to the side of the straight-edge. In addition to the ordinary sighted rule, the telescopic alidade is sometimes used. In this the sights are replaced by a telescope with cross-wires in the eye-

piece. It is very useful for long, accurate "shots", and it is much employed when the plane-table is the only surveying instrument used, as often happens on exploratory surveys.

The plane-table may be used for making a complete survey, and then a base must be measured, its bearing found astronomically, and plotted on the board. A skeleton is built up by triangulation, the sides of the triangles being ruled in and the work growing up on the map *pari passu* with the observation. The

Fig. 65.—Alidade

triangles must be well-conditioned, and the base about as long as the sides of the triangles.

The table is set up in the field at either end of the base, the alidade laid along a line drawn to represent the base, and the table swung round until the distant end of the base comes upon the sights. The table is then *oriented*; that is, it lies in the correct direction. The alidade is then sighted upon such conspicuous points as are to form the apices of the triangles, and rays drawn towards them. These rays should be drawn long enough to pass through the estimated position of the points sighted upon the plane-table sheet, and short extensions should be drawn in at the same time at the edge of the sheet. This is because

it is possible to set the alidade more accurately along a long ray than along a short one. For the sake of neatness and clearness the rays should not be drawn through the initial point. For this work a very hard pencil, 5 H, should be used. It must be sharpened to a long, fine, smooth, round point, and the rays must be as fine as possible, but definite and without unevenness; and they must be drawn so that they would pass accurately through the initial point. In order to keep the near end of the alidade against the initial point, one is often taught to stick in a pin at the point. This is most pernicious. The proper way is to cut the butt end of the pencil to a knife-edge, to hold the pencil firmly standing on the table, the knife-edge at the point and the edge of the alidade against it. Each ray drawn must be labelled for certainty of identification later, and this must be done very neatly, so as to avoid confusion, and in such a manner that there can never be any doubt to which ray the label refers.

When both ends of the base have been occupied, there will be on the table several points fixed by the intersection of rays drawn to them from each end of the base. These are called **intersected points.** One of these is then occupied, the table set up, and oriented. This is to be done by laying the alidade along the ray from one end of the base, and turning the table until that end comes upon the sights, when it is clamped. The alidade is then placed along the ray from the other end of the base, and if that end is now on the sights, the point occupied has been correctly fixed, and the work may proceed; but if not, the whole job must be done anew. The next thing is to draw rays through the other intersected points so far as visible, and if a "pin point" intersection by

the three rays is obtained, the positions of these points are satisfactory; such points as do not have the three rays passing accurately through the same point must be discarded or refixed. No position which is not fixed by two rays and exactly confirmed by a third must ever be used.

Before any point is vacated the detail around it must be sketched in. This is done by eye, aided by short rays drawn to all important points, the distance to these features being paced if very short, taped if longer.

The most important and usual use of the plane-table is for the survey of the detail in an area already triangulated. Before the table is carried into the field, the trig. points in the area are plotted upon it. In the field, the first proceeding is to visit these points in turn, set up the table, orient it by means of the ray passing to another trig, and then check the plotted positions of the remaining trigs. by rays drawn to them. Rays are also drawn to additional points, and when the plane-tabler has visited all his trigs. his sheet will show the detail sketched in about these, and a large number of intersected points.

From this point the work proceeds in the two methods in the same way. The isolated patches of detail must be connected up. This is done in part by visiting the intersected points, but these may not be the most useful, and the principle is to get the maximum amount of detail with the fewest settings-up of the table. As the plane-tabler traverses his area he soon recognizes the points from which he can obtain most material, and he sets up his instrument there, and proceeds to use the method of *resection* for orienting his table and fixing his position. This is the characteristic method in plane-tabling.

Let *a*, *b* (figs. 66, 67) be two points on the plane-table, the positions on it of A, B on the ground. Set up the plane-table at a third point, P. Through *a*, *b* draw rays to A, B, and let them intersect on the table in *s*. Unclamp the table and turn it round a little, and again draw two rays to A, B through *a*, *b*, and let them intersect in *t*. Then the angles *asb*, *atb* are equal, being the angle subtended at the table by AB. By swinging the table a little many times, many angles equal to these could be drawn, and the vertices of them (*s*, *t*, . . .) would all lie on the same arc of a circle of which *ab* is chord.

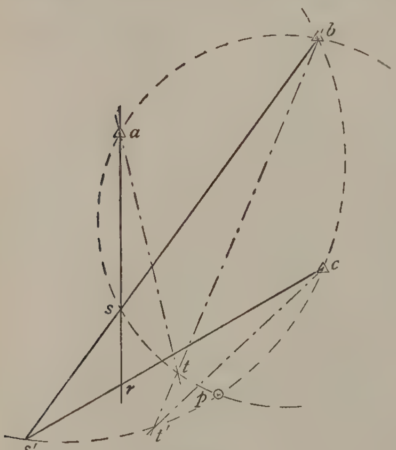


Fig. 66

If, now, C were a third point on the ground, to which corresponds *c* on the table, then when *sb* was drawn, a ray *s′c* might have been drawn through *c* towards C, and cutting *sb* in *s′*; *t′c* might also have been drawn when the table was in position for *tb*, and so on for any number of points. The angles *bs′c*, *bt′c*, . . . are all equal, being the angular distance apart of B and C at the table, and the vertices of these angles lie on an arc of a circle of which *bc* is a chord. The two arcs meet at *b* and at another point, *p*, which is the position of P on the map, because on the map *ab* and *bc* must subtend at *p* the angles subtended on the

ground at P by AB and BC. If the table had been correctly oriented at first, the rays from A, B, C would have passed through the same point, *p*, on the table. As a matter of fact, the three rays make a small triangle on the table, *rss'*. This is called the *triangle of error*. If, however, A, B, C, P all be on

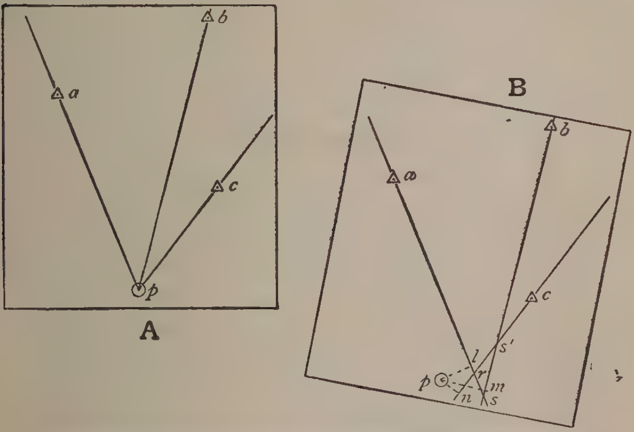


Fig. 67.—A shows Plane-table correctly oriented. B shows Plane-table slewed 10 degrees from correct position. The rays through *a*, *b*, *c*, are parallel in the two positions.

the circumference of the same circle, there will not be a triangle of error; *p* will satisfy the conditions wherever it lies.

Triangle of Error.—The triangle of error is due to the fact that the table is not oriented; it is out of place by a definite angle, and each of the rays drawn to A, B, C is out by the same angle. If this is remembered, all the imagined difficulty of this method of *resection* will disappear. This angle is *pas* or *pbs* or *pcs'*. It throws all the rays out *either* to the right *or* to the left, not some one way, others the other.

In figure 66 they pass to the left of *p*, and are turned away to the right, looking towards A, B, C. Having got three rays and a triangle of error, we must decide where the true point lies, and this is easy. In the first place, the rays divide the space about the triangle of error into seven parts—one inside, the others outside the triangle, as numbered in fig. 68. Applying the fact that the true point must be either to the right or to the left of each of the rays, it becomes clear that in this case it must be in either the space numbered *2* or that numbered *5*. By the same reasoning the student can show that if the triangle of error comes within the triangle *abc*, then the point lies within the triangle of error; if not, without. Now draw *pl*, *pm*, *pn* perpendicular to the rays (fig. 67). Since the angles *pas*, *pbs*, *pcs'* are equal, the triangles *pal*, *pbm*, *pcn* are similar, and *pl*, *pm*, *pn* are proportional to *al*, *bm*, *cn*; or, the distance of the point from the rays is proportional to the lengths of the rays. The position of *p* can, therefore, be estimated, and if one of the rays is much longer than the others, this estimation is all the more easy to make.

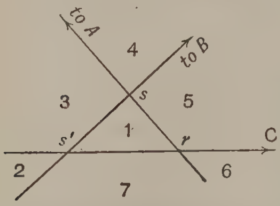


Fig. 68.—The Triangle of Error divides the space about it into seven parts.

The process then is: set up and level the table at the place required. Orient it roughly by estimation, and then select three trig. points on which to resect. To each of these draw a ray through the corresponding point on the table, and from the triangle of error obtained estimate the position of the point where the table is set up. Lay the alidade through this point and one of the trig. points on the table, preferably the

most distant, and swing the table round till this trig. on the ground comes on the sights. Draw three more rays. A second triangle of error may result, but it will be smaller if the work has been well done. From it estimate a new position of the point, re-orient the table, and repeat. This must be continued until no triangle is obtained, but the three rays give a point-intersection. Then a ray must be drawn to a fourth point, and the resection is only satisfactory if this passes cleanly through the same point. Resection enables us to do two things: to orient the table correctly, and to fix the point at which it has been set up. After some practice it can be performed with certainty in two to three minutes. For resection only trig. points and points which have been *intersected* by not less than three rays may be used; the use of previously resected points is not permissible. The method fails if all four points lie on the circumference of a circle. If they do so approximately, one of the trigs. must be discarded and a substitute selected. It is best to choose one trig. very distant, then the danger of the four points lying on the same circle is reduced. Another good arrangement of trigs. is three nearly in the same straight line. The point having been resected, the detail about it is sketched in as it was round trigs. and intersected points. This detail should be shown by means of the regular conventional signs, of which there is a table on Plate II.

The student is warned against using what is called the method of traversing with the plane-table, because it does not give the accuracy of which the instrument is capable. In thick-wooded country there may be no alternative, and it must be used. There is no harm, if it is decided to resect at a point which can be seen from one already occupied, in drawing a ray into that

point before leaving, especially if there is something definite to sight on. This ray may be used to give a rough orientation of the table when the point is occupied, but the orientation must be checked by resection. Amateurs often depend on the trough compass to orient the table. This consists of a narrow rectangular box with a glass top, inside of which swings a magnetic needle. There is a "lubber line" parallel to the long side of the box. The instrument is supplied for fixing the magnetic north and south line when the table is set up. The table having been oriented, the compass is turned until the needle lies along the lubber's line, when a line is ruled along the side of the box, in the magnetic meridian. At any time subsequently the compass may be set along this line, and the table turned until the needle is central. This gives a rough orientation of the table. If a resection be tried, in most cases a triangle or error will be obtained, and correct orientation must be obtained by resection.

Traverse.—In wooded country triangulation may be impossible, and both the main framework and the detail may be mapped by traversing. This consists in running lines of survey, much as in the case of chain survey, but the angles between the lines are measured (e.g. the angle ABC in fig. 56). We cannot go into the matter in any detail (See Appendix, Chapter IV, questions 3, 4). Theodolite traverse consists in chaining the lines and measuring the angles by means of the theodolite. An azimuth having been observed, the angles can be converted into bearings, and latitude and departure calculated as under 4, p. 116. Theodolite traverse replaces triangulation where the nature of the country makes the latter impossible. Traverse does not check itself in the way

triangulation does, but checks may be obtained by taking rounds of angles to points fixed by triangulation or otherwise wherever possible, and by closing the traverse either on the initial point or on points fixed by triangulation. It is often difficult to get long "legs" or individual lines of traverse in wooded country, and short legs mean many angles, and, therefore, slow work and more opportunity of error, while the errors due to bad centring over marks are larger. Traverse work is booked like chain survey, the angles being written in the central column if forward angles, in the offset columns if side angles. Compass traverse is rough work in which the angles are compass bearings, usually taken by means of the prismatic compass or surveying dial, and distances are often obtained by pacing or by time, the average speed of travel being used. Compass traverse may be plotted by protractor, for its accuracy is too low to justify calculating co-ordinates.

Levelling.—In addition to detail, relief must be mapped. This is done in the process of **levelling.** The surveyor who is doing the detail should make sketches of hills and other features from several points of view, as an aid to the work of the leveller, which is the accurate survey of the relief of the land.

If the earth were quite spherical, points on the same level would be at the same distance from the centre of the earth, and heights would be referred to the surface of a sphere whose surface corresponded to what we call sea-level. For the sake of simplicity, we shall assume that the earth is spherical, so as to see more easily the central fact of the matter.

Sea-level is a changeable thing, on account of the rise and fall of the tide, whose amount varies from day to day. At many places the rise and fall of the tide

has been observed for long periods of years, as at Liverpool, and in this country the mean height of the tide at Liverpool is taken as sea-level, to which all levels are reduced. It is about the height at half-water at Liverpool at spring tide. All over the country are "bench-marks", whose height above the accepted mean sea-level have been fixed with great care. These bench-marks are "broad arrows" or "crow's-feet" with a horizontal line at the point, cut into mile-stones, buildings, and other permanent structures. Any fresh levelling can be based on them, and by their means reduced to the accepted "sea-level", otherwise called "Ordnance Datum".

In accurate levelling the apparatus used consists of a level and a levelling-staff. The latter is a long rectangular rod, usually telescopic, in three parts for convenience of carrying, divided from the foot up in feet, tenths, and hundredths of a foot. Sometimes it has a small spirit-level or a plumb-bob attached for the purpose of indicating when the rod is held vertical.

The level is essentially a telescope, with cross-wires in the eyepiece, mounted so as to be moved in a horizontal plane. There is a long sensitive spirit-level fixed rigidly to the telescope parallel to its optic axis or line of sight. The whole is mounted on a plate on top of a rigid tripod by means of levelling-screws. The tripod is set up so that the instrument is as nearly level as can be judged by eye, the feet of the tripod being pushed well into the ground for security, and by means of the levelling-screws it is accurately levelled, so that the bubble of the spirit-level is steady in whatever direction the telescope is pointed. The line of sight of the telescope is now horizontal; it fixes what is called a "horizon" or horizontal line at a definite distance above the earth.

The level is set up and adjusted, and the staff is held vertically with its foot resting on top of a mark whose height above sea-level is known. The telescope of the level is now turned on the staff, and the reading at the cross-wires of the telescope taken. Suppose this is 3·91 ft.; the line of sight of the level is now 3·91 ft. above the level of the mark. The staff is now moved along the line on which levels are to be taken,

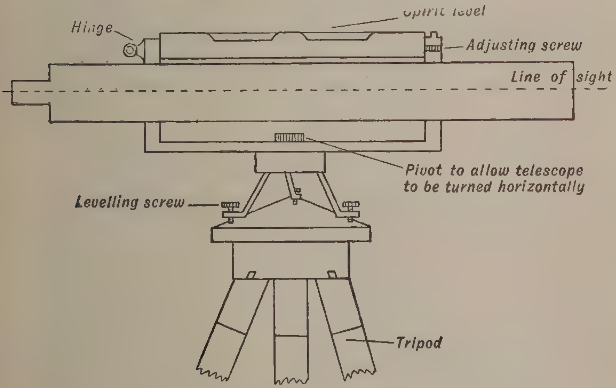


Fig. 69.—Principle of Surveyor's Level

so that it is as far in front of the level as before it was behind. The telescope is now turned on it, and the reading again taken. Suppose it is now 13·46 ft. The foot of the staff is now 13·46 ft. below the level of the line of sight of the level, and it is 13·46 ft. – 3·91 ft., or, 9·55 ft. below the level of the mark on which the line of levels began (fig. 70). It is essential to see that at the moment of observation the bubble of the spirit-level is in the centre of its run. These readings are entered in the level-book. The first reading is called a "back", the second a "forward", reading. The difference between them gives the difference in

level between the points where the staff has been set up, and to find that it is not necessary to take the height of the level above the ground.

The staff is now kept fixed in position, and the level taken forward and set up. It is necessary to take care that the level is not set up in a place where the reading will be off the staff. It is this consideration, together with the necessity not to take too long "shots", and the number of points at which levels are required, that decides how far the level shall be moved. When the level has been set up and adjusted, the staff-man turns the staff so that the figures

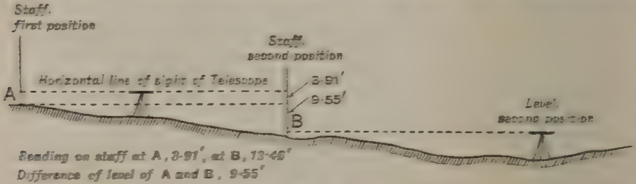


Fig. 70

on it face the level-man. If the staff has been set up simply on loose earth, this process will turn up the soil at its foot, and if the staff is raised off the ground to be turned there is the danger that it may not be placed exactly on the same spot, or that it may not be replaced at the same level. It is, therefore, necessary either to drive a peg in flush with the ground on which to set the foot of staff each time it is set up, or else to stamp a stone about the size of the fist into the ground for the same purpose.

The reasons why the level should be at about the same distance from the staff for the forward and back readings are these. The line of sight of the level, on a much exaggerated scale, is shown in fig. 71, AB. It is at right angles to the radius of the earth at the

point where the level is set up. A is not at the same distance as the level from the surface of the earth; it is farther by the amount A*a*. But if the back and forward positions of the staff be A and B, at equal distances from the level, the errors on the two sides *a*A and *b*B will be equal. Both will be too high by the same amount, and the difference will cut out the error.

Further, a ray of light proceeding from the level passes through air more and more distant from the surface of the earth. It passes, therefore, into higher, and, therefore, less dense air, and is refracted so as to

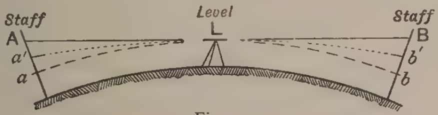


Fig. 71

take a course represented by the curve *a*′L*b*′, and tends to make the readings too low. The amount of bending of the ray depends on the state of the atmosphere as to temperature and pressure, increasing with a higher barometer and with a lower thermometer; but it is never possible to determine it exactly. If, however, the staff in its two positions is equally distant from the level, and not too far distant, so that the state of the air may fairly be assumed to be constant between the positions of the staff, the errors produced are equal and cancel as before. The maximum distance permissible from level to staff is about 200 yd.

Lastly, the spirit-level on the telescope may be out of adjustment; it may not be parallel to the line of sight of the telescope. Readings on the staff in both directions will then either be too high or too low; and if the distance on the back sight be about the same

as on the corresponding forward sight, the errors will once more be equal and cut out in the difference between back and forward readings.

The curvature of the earth introduces an error of about 8 in. per mile, and the refraction a variable error, which is usually much less than this, but may amount to half of it.

It is easy to find the level of points off the line of levels by setting up the staff and reading it at such points. In taking the readings, the back reading is always taken first, the forward last, and the others are taken in between, and are called intermediate readings. These are entered in separate columns in the level-book. There are various ways of keeping a level-book. They each have some advantage, but all have the same end in view, and which is adopted depends merely on the personal preference of the leveller.

Obviously, it is not necessary to begin at a known level. But lines of levels should always be "closed", that is, they should either begin on a point whose level is accurately known, and end on another such point, or they should end at the point at which they begin. This, of course, is so that the error of the levelling may be able to be determined. In the latter case it is enough that at some point on the line of levels should come in a point whose level is known.

There are other ways of finding differences of level, but none of them is so accurate. They consist in measuring the vertical angle between two places whose position is known. If, at B, the vertical angle of A above the horizontal is measured, the angle of B below the horizontal should be measured at A on the same day if possible. This is in order that the errors due to the curvature of the earth and to astronomical refraction, which otherwise must be allowed for in the

calculation of difference of level, may be equal and cut out.

This calculation is very simple. If AC (fig. 72) is the horizontal, and BC the vertical through B, that is, the height of B above A, then AC is the horizontal distance from A to B, which is got by survey. The vertical angle measured is CAB, and BC, the height of B above A, is equal to AC mutiplied by the tangent of this angle. But to this height must be added A*a*, the height of the instrument used above the ground. Also, an addition must be made, to be found from tables constructed for the purpose, to correct the error due to curvature and refraction.

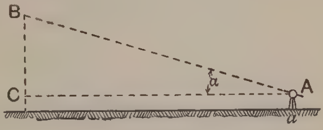


Fig. 72

For exact work the angle CAB is measured on the vertical circle of a theodolite, care being taken to correct the angle for any variation of the adjustment of the levels of the theodolite, which is common in the taking of a round of angles. This is usually done when the horizontal angles of a triangulation are being observed. In that case the horizontal distances between the points are the lengths of the sides of the triangles of the triangulation.

In rougher work the instrument used for taking the vertical angles is called a clinometer. Two of these will be mentioned.

Abney Level.—The first is the **Abney Level.** This is a little telescope, T, to which is attached firmly a protractor, P (fig. 73), which is read by a vernier *v*. This vernier is carried on an arm pivoted at the centre of the protractor, and a spirit-level, *l*, is rigidly fixed at right angles to this arm. There is a milled knob

attached to the arm at the pivot. Directly under the centre of the level there is a "window" cut in the telescope, extending half-way across it, and inside the telescope tube is fixed a small plane mirror, set at an angle of 45 degrees to the line of sight of the telescope. When the instrument is being used to find an angle of depression or elevation, the observer looks through the telescope at the object whose level is required, bringing the cross-wire to the exact point, and turns the knob carrying the spirit-level until he sees the

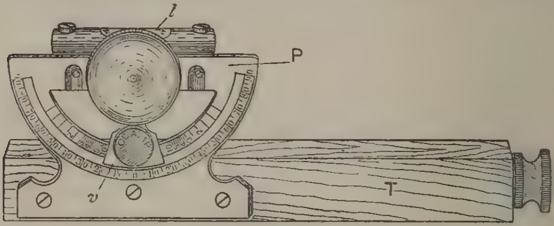


Fig. 73.—Abney Level
T, telescope. P, protractor. *l*, level. *v*, vernier.

bubble reflected in the mirror on the cross-wire of the telescope. The spirit-level is now horizontal, and the reading on the vernier gives the required angle. In this case the distance to the object is measured from the map—from a plane-table sheet, for example,—of the area which is being surveyed, and on which the two positions have been fixed.

Indian Clinometer.—The other clinometer is that usually employed in plane-table work, the **Indian Clinometer**, used first on the survey of India. It consists essentially of a brass plate, standing for stability on three knobs B (fig. 74), to which is hinged at one end an arm. This arm carries a vertical leaf at either end, these being hinged so as to fold flat for convenience of carrying, and to open up at right

angles to the arm. At the free end this arm has a levelling-screw, *s*, and on top a spirit-level, *l*. The leaf at the hinged end of the arm is about twice as long as the other. It is slit vertically, and on one side of the slit is a scale of angles, on the other a scale of tangents of these angles. These are marked to read

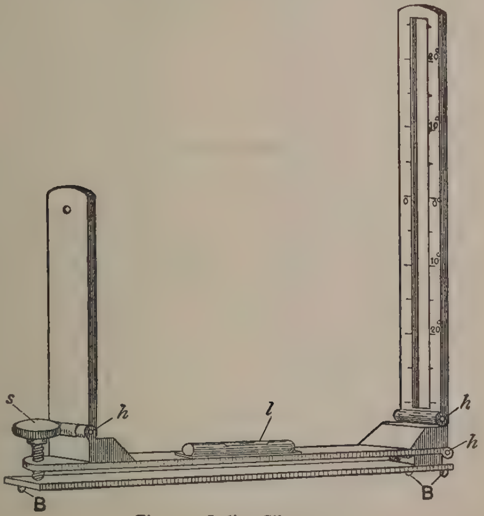


Fig. 74.—Indian Clinometer
h, hinges

upwards and downwards from the middle of the slit. The other leaf, which is the back-sight, has a pinhole at the height of the zero of the scales on the fore-sight.

The plane-tabler employs the clinometer to find the levels of resected points as he occupies them from the known heights of distant points. He is usually supplied with the levels of all the trig. points plotted on his plane-table sheet. Having fixed the position of the point whose level he requires, he lays the clino-

meter along the ray to a trig. and levels it. Looking through the sight-hole of the clinometer, he reads off the tangent corresponding to the image of the distant point on the foresight. He measures the distance on his plane-table, multiplies it by the tangent, allows for the height of the instrument, which is usually 3 ft., and so gets the level of the resected point. Needless to say, it is not permissible to use this instrument, or the Abney level, at such distances that the curvature of the earth is large.

Aneroid Barometer. — Rough differences of level can be obtained by means of the aneroid barometer. The barometer falls about 1 in. for every 900 ft. one rises above sea-level. If the aneroid be read at a known elevation, and then be carried up a hill, the difference in level may be calculated from the difference in the height of the barometer, and aneroids are usually provided with a height scale to render the calculation unnecessary. But as the general atmospheric pressure may have altered in the time between the two readings, it is necessary to have a barometer left at the starting-point and read at frequent intervals, or to run a barograph there. The difference used is that between the readings at the two places at the same time. A rougher method, to which there is often no alternative, is to return to the starting-point after the climb, and again read the aneroid. The difference used is that between the height of the barometer on the hill-top and the average of the two readings at the starting-point. Even this is not always possible; and barometer altitudes, like boiling-point altitudes, are not very reliable (cp. Chapter VII, p. 183).

Contour Lines.—Lines drawn on the map so as to pass through points at the same height above sea-level

are called *contour lines*. If the points whose levels appear on the map are close together, the contours may be drawn in after the points have been plotted, as in fig. 75. The draughtsman must use his judgment. The levels give him an idea of the regularity of the slope of the ground. If it is uniform, the 200-ft. contour line will pass half-way between the levels 207 and 193, and nearer that of 202 than 191. If the slope

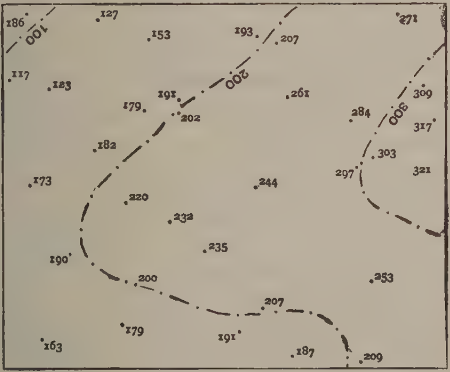


Fig. 75.—Contours sketched from Fixed Levels

were concave the line would pass nearer 207 than 193. Levels to find these sketch contours are often run along straight lines; e.g. from a peak, radiating in all directions; in a valley, along the floor, and across to valley. The plane-tabler sketches contours from his resected points, whose levels he has found.

"Instrumental" contours are actually marked on the ground by numerous points. When the leveller has fixed marks at these points they are surveyed by chain or other methods. Sketches of the ground made in the field are very valuable in guiding the draughtsman in contour drawing.

CHAPTER V

MAP READING

Map reading is the making use of a map, and consists in extracting from the map the information it contains in concise symbolic form. To read a map intelligently it is necessary to be able to judge what amount of information may be expected from it. It is stupid, for example, to attempt to measure accurately an area on a small-scale map which is not even approximately equivalent, or to attempt to measure long distances on an atlas map of a large part of the earth. It is necessary also to be familiar with the symbols commonly employed in maps.

Scale.—The scale of a map depends on the purpose for which the map is required. Maps of cities are required on a large scale in order that all details may appear accurately upon them, and in this country the Ordnance Survey produces maps of such areas on the scale of 10 ft. to the mile. For country districts, where land is of lower value, and a map on so large a scale would show, perhaps, part of the boundary of a field and nothing else on a single sheet, a smaller scale is preferable, and the "25-in. map" (scale 1:2500) is supplied. Poor mountain or upland country does not justify this scale even, and the 6-in. map (1:10,560) is the largest scale map available. No one, on the other hand, studying a city as a whole, and inquiring into its relations with its surroundings, would find the 10-in. map suitable for his purpose; the 6-in., or even the 1-in. map would suit better. A traveller would find the 6-in. map too small for his purpose; it would show on a single sheet far too little,

and the 1-in. map would be preferable, while if he were driving, cycling, or motoring, the $\frac{1}{2}$- or $\frac{1}{4}$-in. map would suit him still better since each sheet shows still more country, and at the same time details all the roads clearly. The broader the interest, the smaller the scale of the map required, and when countries or continents as a whole are to be studied, atlas maps are employed.

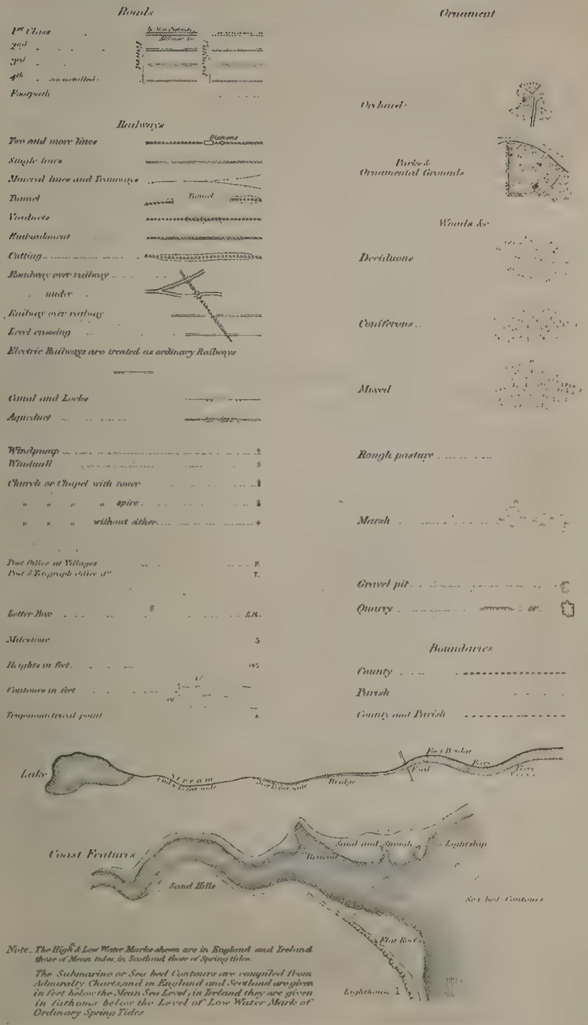
The smaller the scale of a map, the less can be shown on it. Comparison of the 6-in. and the 1-in. map of the student's home district will bring this out. On the larger-scale map small hills and small bends of streams appear which are not shown on the smaller. The map-draughtsman, therefore, when dealing with small-scale maps, must study to select from the information available, all of which cannot be drawn in, such as will give the truest impression of the country. In the older atlas maps the great mountain ranges were shown as long "caterpillars" creeping continuous across the country. Modern work no longer resorts to this device, but while the Alps, for instance, are shown to be a series of parallel ranges, rising in places to great heights, sinking in others to lower passes leading across their barriers, and rivers cutting through them, all their diversity cannot appear on a map of the whole of Switzerland. Again, in order to render details visible, their size on the map has to be exaggerated out of scale. Even on a 1-in. map the roads, if they were true to scale, would be 70 yd. wide, represented as they are by parallel lines about $\frac{1}{25}$ in. apart. In order that roads may be shown distinctly, houses and other objects on the roadside are pushed 20 yd. out of place. In an atlas map on the scale of 1:2,500,000, a road represented by an ordinary fine line is shown as if it had a breadth of nearly 300 yd.

All these limitations must be borne in mind in dealing with maps.

Projection.—We have seen that the properties of a map are determined by the projection employed, but that this is mainly of importance in atlas maps. The graticule (see Chapter III, p. 63) may be drawn in, as is usual in atlas maps, or, as often occurs in topographic maps and charts, the margins of the map may carry scales of latitude and longitude. In the case of such, the graticule may often be completed with sufficient accuracy by joining with straight lines points in the margin in the same latitude, and points in the same longitude. For the map reader the main service of the graticule is to show the true north and south, and east and west directions. It is wrong to assume that on a rectangular map sheet these are the directions of the sheet margins; a moment's consideration of the most usual projections would show this, and one or more sheets of the 1-in. map should be examined in this connection. It is even more necessary to appeal to the graticule for direction in atlas maps; for example, compare the north and south line at Tokio on the map of Asia in an atlas with that at Smyrna, or show with an arrow the direction of north winds at Perth, Western Australia, and Sydney, New South Wales, on the map of Australia. The graticule also shows the relation of the area on the map-sheet, or of any place on it, to the world as a whole.

Conventional Signs.—In old-fashioned maps features were represented by little sketches. These are too cumbrous and confusing, and in their stead a regular, more or less international, set of symbols is employed, and these symbols are known as **conventional signs.** Most of these are familiar and self-explanatory.

PLATE II



Conventional Signs used in One-inch Ordnance Survey Maps

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Many maps have on their margins an abridged list of those used, and the Ordnance Survey publishes complete conventional sign sheets for each of the types of maps issued by it. A selection of the most important of these signs is given in Plate II. Those employed in the representation of the relief of the land, diversification of mountain and valley, hilly country and plain, require special treatment.

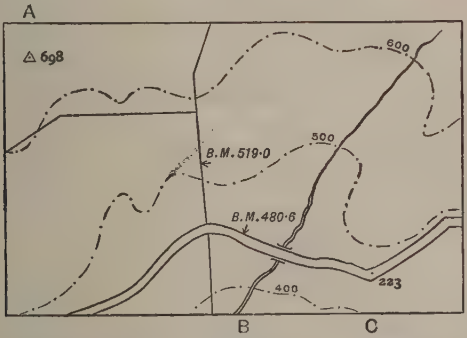

Fig. 76.—Example of 6-in. Map with Trig. Point (under A), Bench Marks (above B), Spot Level (above C), and Contours at 100 ft. vertical interval

Several methods of showing relief are employed, singly or in combination. Not all are suitable for atlas maps, and we shall assume at first that we are considering topographic maps.

The simplest method is the marking on the map of the height above sea-level of conspicuous or definite points. Such information is definite and exact so far as it goes, but it does not enable the eye to appreciate immediately the relief of the land. On the Ordnance Survey maps three kinds of single heights are shown (fig. 76). The positions of trig. points are indicated by dots surrounded by little triangles, and against these is written the height of the point; but there is

not in general any surface mark to show on the ground the position of a trig. point, and it is not permissible to dig up and "restore" trigs. without authority. Bench marks are shown on the map by means of small "broad arrows", with "B. M." and the height above sea-level written against them. On the ground they consist of a broad arrow, with a horizontal line across the tip cut on a building, bridge, gate-post, wall, stone (in open country), or other more or less permanent object. The horizontal line marks the exact level. Newer metal marks are now being erected, in which the level is taken to the top of a rounded stud. Lastly, there appear on the maps, commonly on roads, dots with a height in feet written against them. These are "spot levels", and indicate points which were fixed and levelled at the time of survey, but which are not marked on the ground. All these heights are given above "mean sea-level at Liverpool", which is referred to as "Ordnance Datum"; it is not quite the same as mean sea-level at other parts of the coast.

Contour Lines.—The most comprehensive exact method of showing relief is by means of **contour lines** (fig. 75). These are lines such that "horizontal planes" (really surfaces parallel to the surface of the spheroid, or sphere, or, practically, to that of the sea) at different heights above sea-level would cut the surface of the earth in them. All points on the same contour are at the same height above sea-level. If water were added to the sea so as to raise its level by 100 ft., the shore-line would become the contour of 100 ft. The actual coast-line is the zero contour. Depths below sea-level, or contours of the sea-bottom, are called *isobathic lines*, or *isobaths* (cp. chap. on Climate and Weather: isobars, isotherms, &c.).

The difference in level between points on successive contours of a map is called the **vertical interval** of the contouring, and the vertical interval adopted on any map must depend on the scale of the map and the

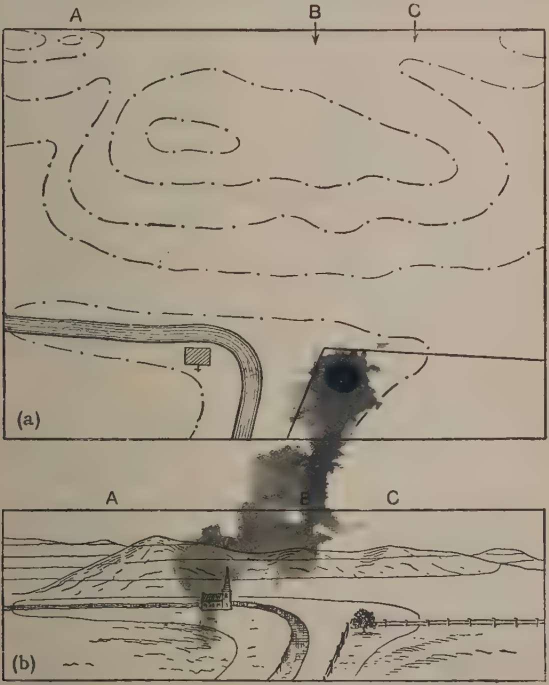

Fig. 77.—*a* is a Map of the Country shown in *b*. The contours show the "under-feature" A, but miss B and C

nature of the country; for the smaller the interval, and the greater the relief, the more numerous the contours, and too many lines would overload the map and obscure detail. The purpose for which the map is required also affects the matter. Contours tell

nothing about the levels between them, and on a map with vertical intervals of 100 ft., like the Ordnance Survey maps, small hills, subsidiary summits, and "under-features" may not be indicated (fig. 77). For engineering and military purposes, such an interval would be much too great; our war maps of France were contoured at a 5-m. ($16\frac{1}{2}$ ft.) interval. Close contouring (i.e. at a small interval for the country) is easy to read, because it amounts to a sort of shad-

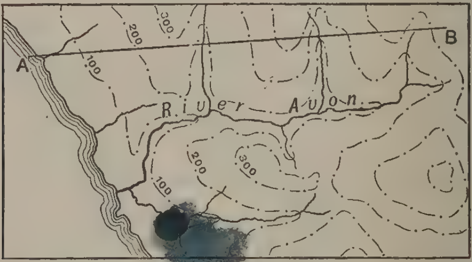

Fig. 78.—Map with Contour Lines at 100 ft. vertical interval. Note how the contours form V's running up valleys

ing, throwing up the relief. **Form-lines** are contours which are sketched merely, or drawn in from a few points of known level. Many American maps, in which detail is scanty, have contours or form lines at small intervals, and they present to the eye an easily appreciated picture of relief.

From a contoured map it is easy to estimate the general slope of the country, and to draw a "section" to illustrate it. Suppose we wish to do this for the country between A and B on fig. 78. Join these two points by a straight line, and plot a graph on an ordinary piece of sectional or squared paper, the abscissæ being the points where the line AB cuts successive contour lines, and the ordinates the heights

of the respective contours above sea-level. The scale of abscissæ will usually be that of the map, for convenience, and the vertical scale, or that of ordinates, will be some convenient one which will require to exaggerate heights, in order to make the relief sufficiently apparent, but should not do so too much. The graph is a sweeping freehand line passing through the points plotted. Fig. 79 shows the changing slope, the average slope from A up to B (that of AB), and the fact that the closer together the contours are on the map the steeper is the slope of the land. When

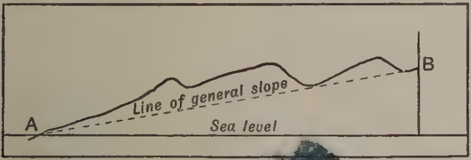

Fig. 79.—Section from A to B in map above

the vertical and horizontal scales of the section are not the same, it is clear that the slope cannot be obtained by measurement from the section without reduction for exaggeration. A section can be drawn almost as easily along a zigzag line, or along a curved one. The student should draw one along the bed of the stream marked *River Avon* in fig. 78. He will produce a longitudinal section of its *thalweg*, or valley bottom.

Streams naturally flow along the steepest slopes available to them, and the lines of steepest slope at each point are called *stream lines*. They are, of course, at right angles to the contour lines, where they cross them.

The appeal of contours to the eye is strengthened in the colour layer system. This consists in giving

the interval between selected contours a wash of colour according to a carefully selected scale of colouring (cp. fig. 80). The colours are usually chosen according to the chromatic scale of the rainbow, beginning on low ground with green, first darker, then lighter as the ground rises. From green the scale passes into browns, light for lower ground, darker for higher, and in very high country the colour often becomes crimson, sometimes white. Bartholomew's ½-in. touring maps are excellent examples of the use of the layer system; indeed they were the first maps on which it was generally adopted. The use of colour layers is also carried out in the "Advanced" Atlas, and in the new *Times* Atlas of the same firm. The addition of colour to contours makes the map a much more striking picture of the configuration of the country, while the information remains definite and accurate so far as it goes. But, in general, as land rises higher the slopes become more steep, contours become more crowded, and the strips of colour narrower; while if the same sheet shows land of great difference in level, the colours available tend to become exhausted. To meet this difficulty there is adopted the device of altering the contour interval, and as this is misleading, the student must be on the watch against it. It is customary, for example, on Ordnance Survey maps to give contours at the following heights: 50 ft.; 100 ft.; and every 100 ft. up to 1000 ft.; every 250 ft. above 1000 ft. Thus the slopes above 1000 ft. appear to be more easy than they actually are in comparison with those below. (Examine and compare the practice in Bartholomew's ½-in. maps.)

Hachures.—The contour system is also the basis of the method of hachuring. Hachures are stream lines

drawn in between the contours. In order to bring out slope they are put closer together the steeper the slope; that is, the closer the contours the more numerous the hachures (often the thicker also), and steep slopes are thus heavily shaded, while very gentle slopes are left blank. It will sometimes be found, notably on French maps, that each hachure is interrupted where it crosses a contour line, so that the contours, which are not printed on the map, appear as white lines. On many maps both contours and hachures are shown, and a very striking and easily read representation is the result. Hachures alone bring out the slopes, but give no direct information regarding actual heights above sea-level, while the reverse holds of contours and colour layers.

In many modern maps the hachures are replaced by stumping, or ordinary shading, and it is the convention that the map shall be shaded as if it showed the country illumined by sunlight coming from the north-west. Good examples of this practice are found in the ½-in. map of the Ordnance Survey, in which contours also are shown in brick-red or brown.

Rapid appreciation of relief is one of the most important acquisitions which must be made by the map reader. He will prefer always to use contoured maps, if possible, on account of the definiteness of the information they give. The contours show the *land forms*, or features, which it is necessary to be able to identify. We can separate right away lowlands and highlands. Land below the 600-ft. contour is usually called *lowland*, land above the 2000-ft. contour *highland*, and land between these limits *upland*. A plain is a "flat" piece of country. Its surface is diversified by low hills, or ridges and valleys, but it is characterized by very low relief. Plains may occur in

lowlands, uplands, or highlands; highland plains, especially if the land falls away fairly abruptly from their margins, are called plateaux (fig. 84). From sea-level or low land, the country slopes upward to a *crest*, or *divide*. Beyond this the land begins to slope downward again. Water flows in opposite directions on either side of the crest; hence the names

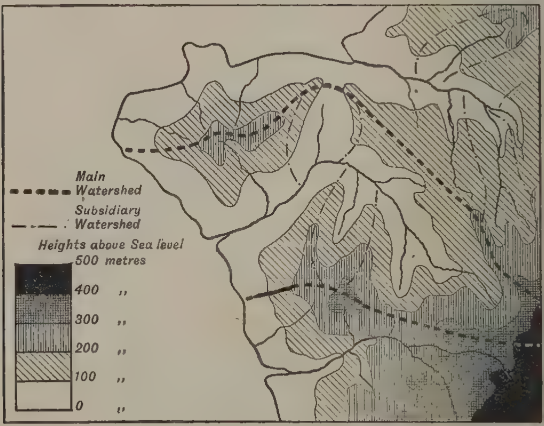

Fig. 80.—River Basins and Watersheds

divide, *water-parting*, and *watershed*. After falling beyond the divide, the slope may become upward again; such converging slopes enclose a *valley*, the bottom of which, the meeting-place of the slopes, is a valley line, or *thalweg*. A given divide or watershed encloses a *basin*, or *drainage area*. Subsidiary divides separate a main drainage area into tributary valleys. Usually a divide is in the form of a more or less irregular V, the top of the V being cut off by the sea, which then forms part of the boundary of the basin (fig. 80). But sometimes the divide forms a

closed curve cutting off the basin completely, and in dry regions, like the Dead Sea area, or the Great Basin of Nevada, U.S.A., or the Basin of Lake Eyre, in South Australia, the waters of the basin drain into the bottom of the area, and evaporation is so much in excess of rainfall that there is no outfall to the sea. Such are *inland*, or *internal drainage areas*. The bottom of some of them, like that of the first named, lies below sea-level, and in such cases we have *sunk areas* or *depressions* (fig. 81).

Fig. 81.—An Internal Drainage Area—the Caspian

Slopes are of all kinds, from a gently rising undulating surface to the frowning precipices of mountain regions. Usually in hilly or upland country they are convex, the slope easing as the summit is reached, while in mountainous country they are concave, with steeper gradients at higher levels. Gently and evenly sloping country is called a tilted plain, and very often such slopes rise evenly and gently until they reach the crest, from which a much steeper slope falls away on the other side. Such a steep slope is called a *scarp* or *escarpment*; similar features are often associated with upland plains or plateaux (cp. figs. 82, 83). Excellent examples of scarp country are found in England south and east of a line joining Gloucester and Whitby. The first scarp begins in the south-west as the Cotswold Hills, and continues north-eastward as the

Northampton Uplands to turn northward in Lincoln Edge. It faces northward and westward, and is called the Jurassic or Oolite scarp[1]. Farther south comes the Chalk scarp,[1] also facing north and west.

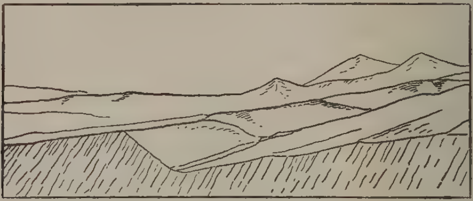

Fig. 82.—Sketch of Scarp and Asymmetrical Valley (in foreground)

It disentangles itself from the low upland of Salisbury Plain as the White Horse Hills, turns toward the north-east as the Chilterns, which are continued by the East Anglia Ridge; in Norfolk bends to run north as Norfolk Edge, and is cut out by the Wash, beyond

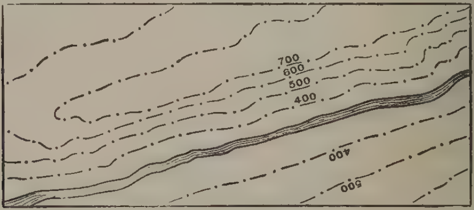

Fig. 83.—Scarp on Contour Map

which it appears running about north-north-west as the Lincoln Wolds. As the Yorkshire Wolds it bends round to run out to sea in an eastward direction. From his map the student will easily trace the chalk scarps of the North and South Downs facing each other across the Weald.

[1] Because of the geological age of the rocks, limestones in both cases, of which they are composed.

Scarps have been of great account in the history of the human race in many regions, and the map reader must appreciate fully their importance. In such country as England the long, gentle slopes gradually rising from the foot of these escarpments divide the country into asymmetrical valleys, the section of which shows one steep side and one gentle, with the rivers flowing generally at the foot of the scarp. The inclined plain permits the settlement of a population, the line of the valley facilitates their migration and communication along it, but the steep scarp presents a barrier to both. Roads and railways tend to follow the line of the scarp, and only cross it where there is a break in it. For the map reader, scarps bring out clearly what is called the *geographical grain* of the country. They show up certain lines which determine the plan on which the physical and human geography of the country has been built up. Rivers which take the easy road along this grain—in this case parallel to the escarpments—are called **longitudinal** rivers; those which break across it are called **transverse.**

Land forms are never regular; even what we call plains have their surface diversified by low, rounded features, and the irregularities of slopes are important. When the slopes rise up to cut off small elevated areas we have mountains or hills. It is customary to restrict the term mountains to features over 2000 ft. high, but practice varies with the type of country, and what we call a mountain in this country might very well be called a hill in the much higher Alps. Mountains may be arranged along very distinct lines, as in the Alps; they are then the highest parts of **ridges** and constitute **mountain ranges**; or they may be the highest parts of generally high tracts of country, as in the highlands of Scotland, and show no notable

linear arrangement, when they are said to form **mountain groups.** From the low ground the irregular edge of a scarp may look like a mountain range, and give rise to a false description. Thus, the edges of the plateau scarps of Africa and Australia

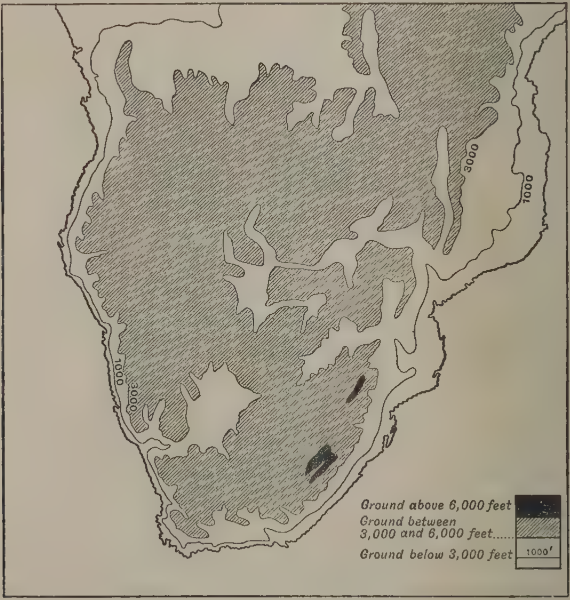

Fig. 84.—The Plateau of South Africa, presenting a steep scarp to the sea, but deeply trenched by great river-basins. Note irregularity of contour interval

are often still wrongly called mountain ranges (fig. 84). The grain of country is easily picked out when shown by the lines of mountain ranges; mountain groups do not often betray it at once. Where the country falls between two mountains, we have a **col, pass,** or **saddle** (from the shape), and in mountainous country these control the routes of lines of communication. In

lower country the same feature is called a **gap**, a name commonly used of breaks in escarpments. Gaps and cols may be looked on as the meeting-place of the heads of two valleys which run more or less in the same line, but in opposite directions. Some additional and rather more familiar terms are explained in the figures accompanying this part of the chapter, and it is essential that the student should study all the definitions in relation to the figures, and should practise identifying similar features in the field in his neighbourhood.

Depths below sea-level are indicated by contours, but in this country the fathom is more commonly used as unit than the foot, while, on continental maps, and many maps used for purely scientific purposes, the metre is used. More will be said on this point in the chapter on charts, but we must consider here the extension of the land under the sea. Round the coasts there is a gentle fall towards deeper water to a depth of about 100 fathoms, after which the slope of the sea bottom becomes rather steeper. This part of the sea bottom above the 100-fathom isobath, and surrounding the land, is called the **Continental Shelf**, or **Platform**, and on to it are continued many of the features of the land. The continental platform may be quite wide, as it is round the British shores, or it may be comparatively narrow, as off the coast of Spain, and on the Pacific coasts generally. The platform is a matter of considerable importance, because the forms of coast-lines are related to its nature, and because the great fisheries are carried on in the shallow waters above it. It is for this reason that the North Sea is such a hive of fishing industry; it hardly extends beyond the continental platform. Maps which include the coast usually show part at least of the platform.

When river valleys extend out on to it, they give the type of inlet, or estuary, called a **ria**. Rias are more or less funnel-shaped, widening and deepening gradu-

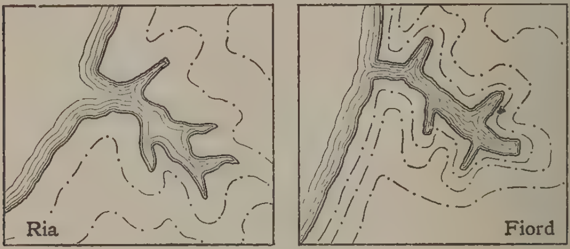

Fig. 85

ally outwards. If they are deep enough, and free from sand-banks, and if they are in a settled region where there is a need for trade, they form important harbours. An inlet with steep walls, and usually

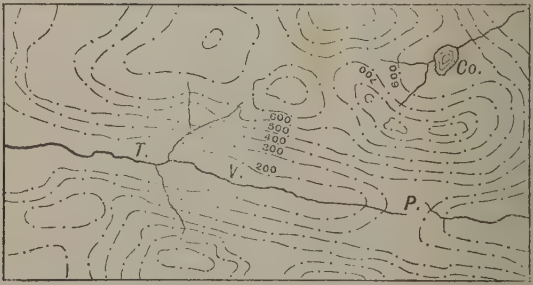

Fig. 86.—Trough Valley (T. V.); Pass or Col, P.; Corrie or Cirque, with lake, Co.

very deep water, is called a **fiord**. Just as a ria is a "drowned" river valley, a fiord is often a drowned **trough** valley (figs. 85, 86). Fiords are found on high coasts, as on the west coasts of Norway and the Scottish highlands. Coast-lines have not always

been permanent, and above the present high-water mark we find, particularly in hilly country, terraces backed by cliffs, much like the present shore cliffs. These represent notches cut in the land when the sea rose to a greater height upon it than it does at present, and are called **raised beaches.** They are frequent on the Scottish and Irish coasts, and are important because they may offer the only flat land available for cultivation and settlement in such rugged regions.

The lines of communication of a country are of importance in map reading, both on account of their own consequence, and also because they are determined by the relief of the land, and shed much light upon it. More will be said on the subject in the chapter on inland transport, but we may remark generally that roads and railways follow the easiest routes, running up valleys, climbing hills gradually by slanting across the stream lines, taking advantage of gaps and cols for the crossing of mountainous tracts. This is more and more noticeable in modern times, when practically all transport is by wheeled conveyance, and the means of locomotion becomes more and more rapid. Steep hills mean slowing of speed, increased consumption of fuel, and less economical working. Hence new and easier roads come to be made, and grades on old roads are improved by filling in hollows and cutting down hills. It pays to spend money in extensive engineering and in making roundabout roadways and railways rather than in fighting with steep hills on short routes.

As examples of the method of reading maps and of the kind and amount of information to be extracted from them, and in order to connect up and amplify what we have said, we shall deal rapidly with two unlike sheets of the 1-in. Ordnance Survey maps.

We do so without any special object, but the student will easily see for himself the different methods to be adopted when using a map with a definite end in view; for example, in the preliminary consideration of the route of a new road or railway line.

2. Special sheet of Salisbury Plain, including sheet [illegible] and parts of sheets 111, 112, 121.

The map is printed in colours for distinctness, and a short list of conventional signs is given in the margin of the map. It has contours at [illegible] intervals, and some heights and [illegible], but no hill shading. In [illegible] the distances between the contour lines. [illegible] squares arranged in rows, each distinguished by a letter, and in columns distinguished by numbers. This is for convenience of reference. Thus we can refer to the village of [illegible] as [illegible], i.e. it is in the square of row [illegible] in column [illegible]. This system of squares is commonly called a grid. It is not to be confused with the graticule. The lines of the grid are parallel to the edges of each sheet of the map, and [illegible] north and south, south of east and north of west, as can be seen from the scale of latitudes and longitudes [illegible] in the margins of the map. The map is about [illegible] in. by [illegible] in., and therefore covers an area of some [illegible] sq. miles.

The land lies some height above sea-level. It is highest in the north (over [illegible] ft.) and lowest in the south ([illegible] ft.), and higher in the west than in the east, though towards the south-west corner the land is again rising. In general, however, omitting river valleys, there is a gentle slope to the south and east, and the course of the longer streams is southward and eastward. The general rather high level is broken by several broad valleys which carry streams, and converge on Salisbury, while the surface is undulating to some extent; it is open country. The absence of chalk-pits and [illegible] suggests that it is chalk country. In general the valleys are not symmetrical, but have steeper slopes or scarps, on their southern sides [illegible]. Except for the main streams, there is little running water, and in the middle of the downs there are many dry valleys without streams (which is characteristic of [illegible] chalk country, the water tending to follow underground courses [illegible]) [illegible] D. 4. Woods are plenty, small and scattered [illegible]

how often the word "copse" occurs); farms are not numerous on the upper land, which probably only produces poor pasture, and carries chiefly sheep.

The main roads follow the chief valleys, or cross the downs by climbing up the valleys to the higher land. One main road runs across the middle of the sheet from east to west. It takes advantage of a belt of lower ground, however, and makes use of subsidiary valleys. Two good roads follow low ground northward from Salisbury to Devises, while there is a third parallel to them crossing right over the down between. It, however, is shown as an indifferent road in poor state of repair for the most part. The reason is clear. In the old days when transit was not rapid, and the motor-car was not in the land, the hill road was shorter, and good enough. The road to the west of it is a rather longer, but more level road, improved in recent years, which has supplanted it. It is interesting to compare the Roman roads, which are numerous in this sheet, with the modern, e.g. that running a little north of west from Sorbiodunum, or old Sarum (J 9, 10), or the Port Way, passing north-eastwards from the same place, and now partly followed by a newer road and the London & South-Western Railway (but in a cutting). They run dead straight up hill and down, because a slope that makes wheeled traffic difficult is of less consequence to marching legionaries than a long road even on a less slope. Railways are almost confined to the south of the sheet, follow the valleys like the roads, and also like them, tend to converge on Salisbury.

The map is rich in information concerning the human occupation of the area. There are numerous antiquities, barrows or tumuli, burial mounds erected by the early peoples who lived there before the dawn of history: long-shaped barrows are often distinguished. There are also so-called druidical remains like Stonehenge (F 9), and circular earthworks or rings (H 11), earthworks associated with the historical Early Britons (Casterley Camp, B 9), Roman roads and settlements (Sorbiodunum). The names of many ruined mediaeval castles are also to be seen, and the famous Old Sarum. These show that this was one of the earliest occupied parts of England, and that the human history of it has been long and continuous. In modern times its prosperity has departed, for the map gives no evidence of other industry than probable arable farming in the valleys and sheep pasturing on the downs, while the only town of note is Salisbury, concerning which one can clearly deduce that it is a market-town purely,

and a cathedral city. Villages and hamlets are to be found in the valleys only, and on the downs the chief settlements are military camps.

2. Ordnance Survey of Scotland, sheet 45, Oban. Coloured edition.

This map is printed in colour. It has contours at 50 ft., 100 ft., and every 100 ft. to 1000 ft., above that at 250 ft. interval. Hachures in brown. No graticule, nor indication of latitudes and longitudes. Grid as in last sheet, but only indicated in margins. "grid north" and sheet lines run about 3° west of north and east of south, as indicated, together with magnetic north and declination, at top of east margin.

In contrast with the Salisbury sheet, this shows a rugged area, mountainous in the east and part of the coast-line. Country of two distinct natures appears, the boundary being Loch Awe, its arm into the Pass of Brander, and the line of Glen Salach. To the east the country is higher, more rugged, and less crossed. The lower country to the west shows traces of banding from north-east to south-west. From this we may conclude that the ground-work of the two areas is quite different (as a study of a geological map would reveal; a geologist would see at once from the topographical map that the material of the two types of country differed). Several distinct lines are conspicuous on the map. The first is the N.E.–S.W. line already noticed. It is most marked in the shape and arrangement of the sea-coast islands and peninsulas in the north-west of the map, but it appears also in the arrangement of the valleys and sea- and fresh-water lochs elsewhere: Glen Strae, Upper Loch Etive, Loch Feochan and Nell, Loch Awe. The next runs N.N.W.–S.S.E.: Pass of Brander and branch of Loch Awe, Middle Loch Etive, Lower Loch Creran. The third is W.–E., and is less noticeable, but is shown by Loch Scammadale (J. 11. 2) and Lower Loch Etive. These are the structure lines of the country, and the first, the most marked and most important, is very noticeable in the general plan of Scotland; it is the line of the Great Glen (Caledonian Canal), the Highland Border, the border of the Southern Uplands, and the Midland Valley and Strathmore, as well as of great stretches of the east coast, and of many of the long, narrow sea and inland lochs. The student should take the heights of rows of peaks along this direction, and at right angles to it, calculate them, and draw his own conclusions as to the general slope of the country.

Probably the nature of the lochs and valleys will strike the student next. The former, both sea and inland, are long and narrow, and their straight shores take sharp bends, mostly to change from one system of ruling lines to another. Loch Etive is the most remarkable in this respect. More detailed examination of the underwater contours, or isobaths, in them shows that the sea lochs are often deeper farther inland than at their mouths, separate basins being bounded by shallower bars or *sills*. This is characteristic of fiords, and these sea lochs are true fiords. The same characters are seen in many valleys. The valleys in general have flat, gently sloping floors, and some of them are occupied by strings of lakes. If the sea-level rose a comparatively small amount (how much?) Loch Feochan and Loch Nell would be joined into a sea loch with such a deeper inner basin on the present site of Loch Nell as is actually found in Loch Etive. The slopes of the valley sides are rounded, and are convex: this is exaggerated by the change in contour interval above 1000 ft. At their heads the gentle slope of the valley floors rapidly steepens, and they end in roughly semicircular amphitheatres in the hillsides, called *Coire* on the map, and known as corries or cirques. These cut the mountains into narrow ridges and spurs (e.g. the Ben Cruachan Mass), or, where the heads of two of them meet from opposite sides, into separate peaks. Sometimes the heads of two valleys meet at lower levels in a rounded saddle (line of Gleann Salach. Glens Noe and Mhoille), opening a *pass* for communication through the hills. These rounded forms, the trough-like cross-sections of the valleys, and other features suggest to the physical geographer the action of moving ice. Other evidence of this is given by the hanging valleys, such as those tributary to the Pass of Brander. The Allt Cruachan and the Allt Brander rise on the steep sides of corries, flow over their flat bottoms and then plunge down the precipitous sides of the Pass, probably in cataracts and waterfalls. Usually streams join rivers from either side in courses that near the confluence are at the same level, and slope at about the same rate as the main stream; but in this case the mouths of side valleys "hang" high above the main one, and from them the tributaries are poured over the edge of steep cliffs. Such side valleys are called *hanging valleys*, and the main valley is said to be *over-deepened*. Most of the great valleys on the map are over-deepened, and this is often ascribed to glaciers of past ages. Such glaciers leave behind them great "dumps" of sand, mud, and boulders, which form hillocks too low and

small to be shown on a 1-in. map, but lakelets collect in the hollows among these tumbled mounds. Sometimes these are naturally drained, or filled up by the growth of peat; and the lochans and bogs of the Moss of Achnacree (D 2), and pools like those on Meall an Laoigh (C 12) are probably relics of them. Such curious incidents of drainage as that from Loch an Lair (A 7) are often due to dams of glacial material (cp. also H 5, 6).

Of great importance to the area are the shelves round the coast to be noticed by close inspection of the contours. These may easily be studied by drawing sections, for the steep slopes of the hill-sides are notched or terraced about the levels of 50 ft. and 100 ft. by the raised beaches, which are common on the coasts of Scotland, and are well marked on Lower Loch Etive and elsewhere. They are betrayed also by the clustering of dwellings and townships on them (e.g. Taynuilt).

Woods are scanty, and are confined to lower ground in valleys, the shores of lochs, and, generally, to the west and to sheltered places. It is not hard to decide that the higher ground will be covered with heath, and the lower with heathy pasture. Such woods as there are are "mixed", and probably largely artificial.

As to human geography, there are antiquities showing that the area was fairly early occupied. There are none of the barrows of the earliest inhabitants of the land, which are seen in the Salisbury sheet, but ancient British forts (*Dun Mor*, E 5), stone circles (H 7), Celtic churches and cairns (D 4), and churches and castles of later date remind us of the incidents in the history of the West Highlands. These, like the modern dwellings and works of man, are on or near low ground, the deltas built out into the lochs by tumultuous streams, the raised beaches, and the flat floors of the valleys. Of modern industry there is little trace (but cp. the mineral railway on the south-east slope of the Cruachan), and it is doubtless confined to sheep-farming, crofting, and fishing on the coast; while sport, no doubt, purveys part employment for the inhabitants. Communications are scanty, whether by road or rail. The single railway follows the deep valleys leading to Loch Awe, the shore of the loch, the Pass of Brander, and thence the raised beaches to Oban and Ballachulish, and the chief road the same route. The coastal strip is settled, but without a doubt owes this and its main communications to the sea. Settlement has only taken place where communication is possible, and hence the deep remote valleys have few houses.

CHAPTER VI

CHARTS: THEIR CONSTRUCTION AND USE

The meaning of the word "chart" is not limited to the maps which are employed by the mariner in navigation, but that is the sense in which it is used in this chapter. Charts have two chief uses for the sailor: first, to lay down the course a ship is to follow on the open ocean, to mark off the actual course the ship follows, and to keep exact count of her progress from day to day; charts used for this purpose are called "sailing charts": second, as guides when the ship is close to land, to enable her to avoid dangers, to "make land" correctly, and to enter ports safely; charts used for this are "pilotage charts". Charts differ from ordinary maps in many ways. One striking difference is the fact that the only details of the land given are such as can be seen from the sea: the nature of the coast-line, prominent rocks, hills (with their heights), and, generally, such natural features and buildings as serve as landmarks and guides to the sailor. The system of conventional signs is different from that used in ordinary maps. Contours on land are not common: relief is indicated by hachuring only; there is a whole set of special symbols for indicating marine features, the depth of the water, and the nature of the bottom, buoys, lights, and other matters of importance to the sailor. For his guidance it is customary to add in the margin sketches of the appearance from the sea of important landmarks, harbours, and stretches of coast, so that he will have no difficulty in identifying them with certainty.

Projection.—The projection universally employed for charts is the Mercator, and that for the reasons given in Chapter III. But in the construction of charts the plans are first laid down on the gnomonic, because it is customary to plot angles and distances direct in this work, and not to use the methods given in Chapter IV. The distances, we have seen, are measured along great circles, and in the gnomonic projection great circles become straight lines.

Marine Surveying.—In hydrographical survey, as survey for the production of charts is called, the preliminary framework is obtained by triangulation, as is done for maps. But many of the observations are made from the ship, and theodolites cannot be used on board on account of the motion of the vessel; hence the sextant, with which the sailor is more familiar, is the usual measuring instrument. Ashore the theodolite may be used, but the type employed in practice is a rough instrument compared with the refined theodolites used by the land surveyor, and the sailor pins his faith to the sextant. Stations are marked ashore just as in topographic survey; for floating signals, the ship and buoys securely anchored are taken. Free use of astronomical observations is made, and the base, by force of circumstances, is often so roughly measured that it may be preferred to adjust the triangulation to astronomical work.

In laying down his triangles on paper, the surveyor uses the method of chords. A protractor is at best a rough instrument. With a large ordinary one, angles may be set out to $\frac{1}{2}°$ or $\frac{1}{4}°$, and special protractors, provided with verniers, are made to permit of angles being set off to single minutes. These are hard to place accurately along a line. The method of chords depends on the fact that in any given circle

n angle of given size at the centre subtends a chord f fixed length. Let the student draw a fair sized ircle, and any radius of it. From the outer end of he radius let him mark off and draw chords equal o, half, and quarter, the length of the radius, and neasure the angles subtended at the centre of the ircle by these chords. He will find them to be 60°, 9°, 14½° respectively. In mathematical tables are iven tables of chords, showing what fraction of the

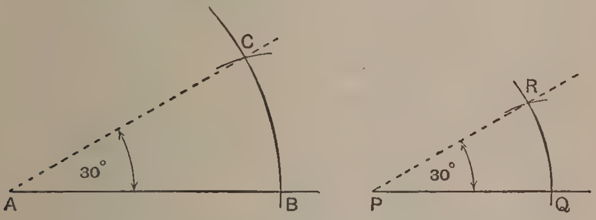

Fig. 87.—Angles and Chords

It is required to set off an angle of 30° by the method of chords. From tables, chord for 30° is 518; i.e. 0·518 of radius of circle. For a circle of 1½-in. radius the chord is therefore 0·78 in. (BC); for a circle of 1-in. radius, 0·52 in. (QR). The angles at A, P are both 30°; but they would be more accurately set off from a radius of 10 in. or more.

adius is the chord which subtends a given angle at he centre of the circle. Suppose we wish to lay off n angle of 48° 20′. The table shows that the proper hord is 0·8188 of the radius. Suppose we decide to se a radius of 5 in. The length of the chord will hen be 4·094 in. Draw a line rather over 5 in. long, nd with radius 5 in. describe an arc of a circle about centre marked near one end of the line. Then with ividers lay off a chord 4·094 in. long, and join up vith the centre of the arc (cp. also fig. 87). Now we annot mark off the 4·094 in. correct to less than 01 in., and this means a probable error of some 0 minutes in the angle, allowing for unavoidable

errors of drawing. If, however, we make the radius 20 in., the chord becomes 16·376 in., and an error of ·01 in. is equal to only about 2 min. in the angle. Thus, in laying off angles, one must use the longest chords the paper will allow.

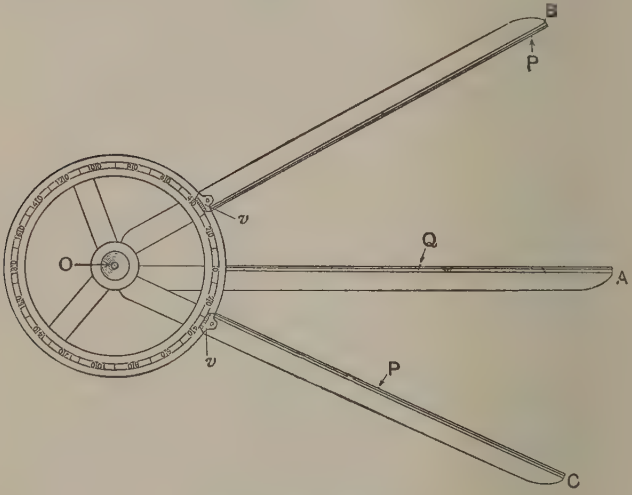

Fig. 88.—Station Pointer in Use

v, *v*, Verniers fixed to movable arms, B, C, and provided with clamps and slow-motion screws not shown in the figure. A, arm fixed to circle. P, Q, R, points on a chart to which angles have been observed by sextant. The position of the ship is given by the pin-hole, O, at the centre of the instrument. (The scale is shown divided to 10° only for clearness.)

Land detail and the fixing positions at sea need not detain us further, because the methods have been explained in Chapter IV, except that the instrument, the station pointer, used for plotting resections from angles observed at a point to fixed points of the survey, demands mention. This consists of three straight, narrow, brass arms a foot or more long, and bevelled on one side like a rule. Of the arms,

one is fixed, the others are pivoted at one end, so as o move in a horizontal plane. Verniers are attached so that the arms can be spread with some exactitude o the angles observed. The angles having been set on the instrument, it is adjusted on the chart so that he arms pass through the three points observed, and he position of the pivot marked as that required. See fig. 88.)

The coast-line, rocks, buoys, lights, &c., having been fixed by ordinary survey methods, it remains o obtain the other information required on charts. The chief concerns the tides: the time of high and ow water, the amount of rise and fall at spring ides and neaps, the direction, speed, and duration of idal currents: and the depth of the water, particularly near the shore, rocks, banks, and shoals, where it is shallow, and the nature of the bottom—information summarized in the sea use of the word "soundings". When the survey is taken in hand, the tidal observations are begun at once, and are usually carried out by a special party stationed at a favourable place for a period of at least a fortnight, because in that period there occur a set of spring tides and a set of neap tides. The sounding is also carried out concurrently with the other work.

Tides.—Tides are observed by means of a tide gauge. In its simplest form this consists of a vertical pole, so placed that it stands on a bottom which is never uncovered at low tide. It may be anchored, or fixed against a rock or pier, and it is marked off in feet and decimals of a foot, or in metres and decimals. The gauge must be fixed in a sheltered spot, so that the waves shall not make the reading difficult. If no such place is available, a pipe similarly fixed is used instead, the water gaining access by holes bored some

way above the foot, but below the level of the lowest tide. Inside the pipe is a float, which carries an indicator, often like that used in water-tanks on railways. Still another type of gauge works on the same principle as the aneroid barometer, the changes of pressure due to the rise and fall of the sea bearing on a closed drum or box. More elaborate tide gauges, like those permanently installed at ports, such as Liverpool, make a continuous record of the height of the water by means of a pen writing on a roll of paper kept moving at a known speed by clockwork (cp. the record made by the familiar barograph), but the simplest forms have to be visited and read every hour regularly, and near the time of high or low water every few minutes. The time of high water at a port varies, but more or less regularly, every day; it occurs at the same hour on the days of new and full moon each lunar month. For any port this is called the "establishment" of the port, and it is written on charts as "H. W., F. & C." (with the time)—high water, full and and change (of the moon). From this, knowing that successive high or low tides occur at intervals of about 6 hours 25 minutes, the sailor can tell approximately the time of high or low water on any required day. The chart also gives the amount of rise and fall of the tide at its greatest, that is, at the time of spring tide. Further information on tides will be found in Chapter IX.

Sounding.—Sounding in shallow water is done from boats, the position of each sounding being fixed by resection, or other convenient method. Soundings are usually made in lines, and so it is sufficient to place marks ashore to indicate the line to the coxswain, so that he may keep the boat on it. A single cross bearing, with a second for a check, then fixes the point

(cp. Appendix, Chapters VI, IX, qu. 9). A hand-line is used in the boat; this consists of a piece of stout line attached to a lead weight weighing 7 to 14 lb. according to the length of the line. The bottom of the "lead" is hollowed into a cup. This is filled level with tallow, so that when bottom is struck a sample of the deposit there may adhere to this "arming" and be brought up. Distinctive marks of leather or bunting, are spliced into the line at certain customary fathoms of length measured from the bottom of the lead, and the leadsman being familiar with these is able at once to give the depth of water. He stands with the lead swung from about a fathom of line in one hand and a coil of line in the other, the end being made fast to the boat. Leaning outboard, he swings the lead fore and aft with ever-increasing speed until it swings vertically in a complete circle, and at the proper moment he lets go, so that the lead strikes well ahead of the boat, and, the line being slack, the weight is free to reach the bottom. At once he gathers up the slack so that, as the boat comes over the lead, the line will be taut and vertical, with the lead on the bottom. If a mark, say the 7-fathom mark, is at the water surface, he sings out, "By the mark, seven!"[1] If the line does not enter the water at a marked fathom, but he estimates 12 fathoms is the depth, his call is, "By the deep, twelve!" He estimates halves and quarters of fathoms, calling, say, "And a quarter, six!" "And a half, nine!" Hand sounding is used in shallow water from ships when they are approaching port or leaving it, but it is laborious, and slow if the depth is near, or over, 20 fathoms.

Deeper soundings are made from the ship by means

[1] The customary marks are at 2, 3, 5, 7, 10, 13, 15, 17, 20 fathoms.

of sounding machines. The machine consists of a drum, on which is wound the fine steel wire used for the work (fig. 89). This drum can be turned by hand or by power for winding in the wire. The rate at which the wire runs out is regulated by automatic brakes controlling the drum. From the drum the wire passes over a pulley of known circumference, and the number of turns the wire causes the wheel to make gives the length of wire run out. The turns are

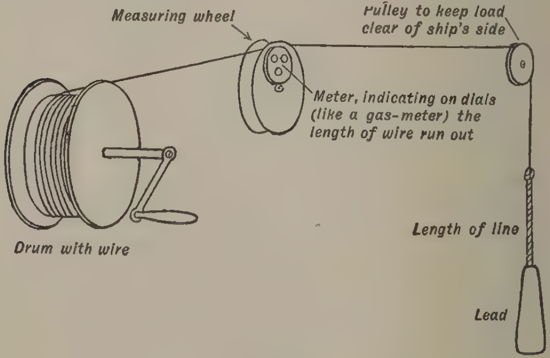

Fig. 89

counted by a train of toothed wheels just as a "speedometer" counts the number of turns of the wheel of a bicycle or motor-car, and in the one case length of wire run out is indicated by hands on a dial, just as the distance travelled is shown in the other. A spar is rigged out well clear of the ship's side, and the wire is passed over a pulley which can be run out on the spar. To the end of the wire is attached a fathom or so of line to prevent the wire twisting and "kinking", and this is fixed to the lead. For accurate work, in order to have the wire vertical, the ship must be stopped to sound. The lead is dropped and

allowed to carry out the wire. The slackening of the wire shows when the bottom is reached, and, in deep soundings, the easing strain of the weight causes the automatic brakes to stop the wire running. In either case the depth is read on the meter. For very great depths, running from 1000 to 6000 fathoms or so, a lead is not used; in its place is a brass rod or pipe, fitted to carry heavy weights, which are increased according as the water deepens, and with devices for taking up a sample of the bottom water and for recording its temperature. When the bottom is reached the weights are freed, and remain on the bottom, to the saving of time and labour in winding in wire. If moderately deep soundings are made when the ship's speed is reduced, but not stopped, a fair approximation to the true depth can be made by observing the inclination of the wire when the meter is read and correcting for want of plumb by means of tables; or a special dial graduated by the results of experiment may be used. An ingenious device for sounding from a moving ship has been devised by the late Lord Kelvin. In the sounding rod is placed a narrow glass tube, some 18 in. long, closed at one end and coated on the inside with red bromide of silver. The tube is so narrow that as it is lowered into the water, mouth downward, no air escapes, and, as it were, a piston of water is forced up into it by the increasing pressure. The salt in the sea-water changes the bromide of silver into the white chloride, and the depth is obtained when the tube comes to the surface by measuring on a scale, graduated to show depths, the distance water has penetrated the tube as indicated by the change from the white internal coating to red. This depth depends not on the length of wire run out, but only on the depth of water above the mouth of

the tube. The machine also carries a dial, and it is customary to take most of the soundings by reading on the dial the length of wire run out, and noting the angle by which it is out of plumb. At regular intervals a tube is used as a check on the work generally.

Submerged rocks are very apt to be missed in lines of soundings. They can be detected with certainty only by "sweeping". This is done exactly as mines are "swept" in time of war, and cannot be further described here. Another sounding device is the "submarine sentry", a kind of submarine kite, which can be towed along at any selected depth in the water. It carries a tripping arrangement, which frees one of the lines attaching the towing rope to it, and allows it to come to the surface whenever it strikes bottom, just as a kite will fall if its attachment to the twine goes wrong.

Charts. — To return to actual charts, these are of several kinds, adapted for different purposes, and differing chiefly in scale. **World charts** are general diagrams of the world as a whole, on which are shown such general information as the variation of the north and south direction as given by the mariners' compass from the true north and south, coaling stations, telegraph cables, and main signalling stations. **Ocean charts** show large sea areas like the North Atlantic, showing little detail of coasts beyond the chief ports, and serve for laying down courses in the open sea. They are on a scale still small, but greater than that of the world charts. On larger scales are **General charts**, showing limited areas, such as parts of the western seas of these islands, on each sheet (fig. 90). Their scales are up to 3 in. to the mile, but of course, on account of the projection, the scale varies somewhat in different parts of the sheet and in different directions.

These charts give much more sea and land detail, and are used in coastwise sailing, and in approaching land from the ocean. They may have sketches of land

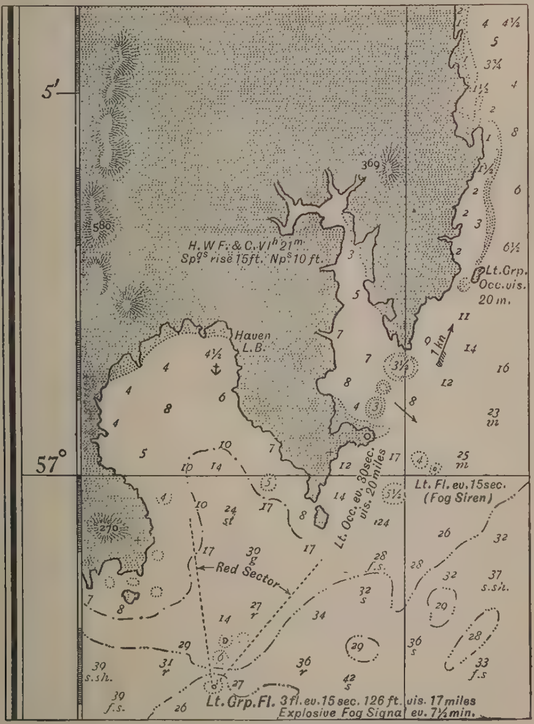

Fig. 90.—Representation (simplified) of portion of western margin of a Chart. The scale of degrees and minutes is continued right round the actual chart

detail in the margins, and larger scale plans of the less important harbours and of inlets to which resort may be had for shelter in stress of weather, as insets. Finally, there are "plans" of recognized and fre-

quented harbours on still larger scales, and with still more detailed information (fig. 91). They vary in scale according to the importance and intricacy of the place,

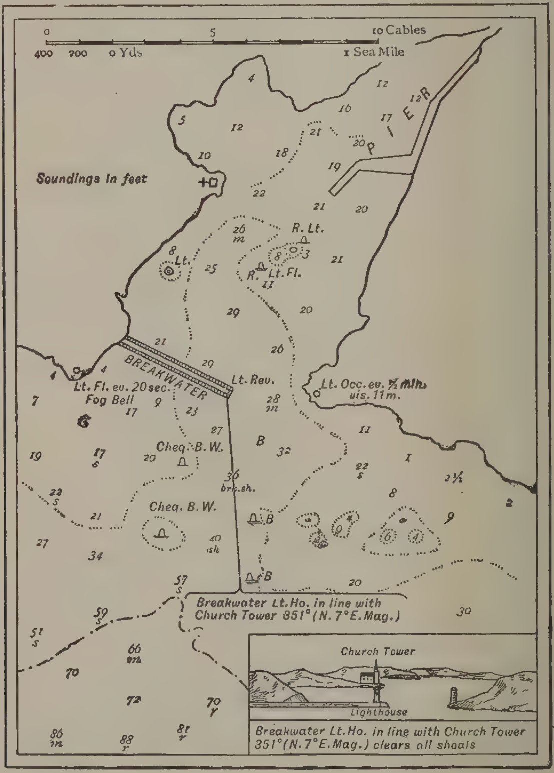

Fig. 91.—Representation of a Harbour Plan, amplified and reduced

but 6 to 10 in. to the mile is usual. A chart covering a large area cannot truly be said to have a definite scale (see Chapter III), and the only scale provided on such is that of latitude and longitude in the border of

the map; it is divided to minutes where practicable. But the plans of small areas, such as ports, carry ordinary scales of distance on which measurements taken at any place and in any direction can be laid

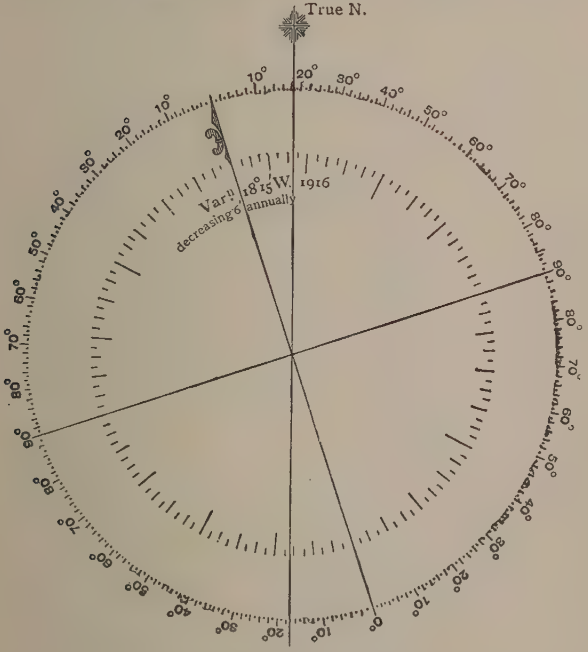

Fig. 92.—Chart "Compass"

down. Soundings in these plans are given in feet, not fathoms.

Direction is indicated on the chart by means of "compasses" engraved upon it (see fig. 92). These consist of two concentric circles. On the outer, true north is shown by a star, magnetic north by an arrow, or fleur-de-lis, on the inner. The outer circle is

graduated in degrees, beginning at magnetic north and south, and numbered up to 90° at magnetic east and west; the inner circle in points, half, and quarter points (magnetic), which are not named. Across the magnetic north and south line is written the variation (see Chapter IX, p. 255) for a definite year (year given) and the rate of change of the variation. Several compasses appear on each ocean or general chart, because of the change of variation from place to place.

The most striking feature about a general chart or a plan is the bewildering array of figures scattered thickly over the water. These are soundings, and are written at the points to which they refer. In shallow parts, and near dangers, they are as numerous as they can be made without becoming unreadable. The figures indicate the shallowest water that occurs at each point; that is, the depth at low water of spring tides. Letters associated with them indicate the nature of the bottom; thus, "47, f.s." means that at low water of spring tides 47 fathoms of water may be expected at the point, and that the bottom is fine sand. The symbols used are shown in the margins of charts. Soundings are of use to a sailor in two main ways. Suppose a captain wishes to take his ship, drawing 22 ft. of water, into a small harbour in front of which is a bar covered to depths indicated by the soundings, 4, 3, 3, $3\frac{1}{2}$, 3, 4, $4\frac{1}{2}$, written over it. At low water of springs there are only 18 ft. of water over parts of the bank, and so he cannot clear it at low tide. But, he learns, the tide rises 12 ft., so at high water he would have at least 30 ft. of water, and could get in with 8 ft. to spare. Suppose, however, there was a sea running. His ship would be very liable to "bump" the bank in passing if she were let down in the trough of the waves, and the margin of safety would not be enough

to justify him in going in under such conditions. Again, suppose a ship is near land, but in thick weather, so that she has no way of determining her position. The captain begins sounding continuously. If he finds that the water begins to shoal considerably he concludes that he is approaching the land, or some danger, and heaves-to or anchors, to await clear weather; or, if he is on a lee-shore, he stands off to sea for safety. If he knows the coast he may proceed cautiously. Thus, imagine a ship steaming round the north of Ireland to enter the Irish Channel and overtaken by a fog.[1] The course is a little south of east (true)[2], speed is 10 knots, and soundings are made every half-hour. The depths are 33, 29, 42, 58, 68, 18, at points some 5 sea miles apart. The last sudden shallowing gives alarm. Speed is dropped to "dead slow", and soundings taken much more frequently, but the water continues to shoal. It is concluded from the nature of the soundings that the ship is near the "dangerous over-fall" of the Middle Bank. A boat might be lowered and sounding carried on from her in order to "feel the way", the ship lying-to meanwhile, if the weather is fine and seems settled, and eventually standing off in a direction in which the water is found to deepen, say to south-west. After half an hour's steaming, it might be considered safe to alter course to east-south-east and proceed cautiously. The position of the ship is, of course, always roughly known to within, say, 20 or 30 miles, because a "dead reckoning" (see Chapter IX, p. 261), or the distance by log sailed on each compass course, is always kept. It can be fixed more exactly by soundings. Suppose the first sounding gives "51, sh." The chart is

[1] This may be followed on Chart, Irish Channel, Sheet 1, No. 1825A.

[2] True or geographical direction, as opposed to magnetic, or direction from the compass.

searched in the neighbourhood of the assumed position of the ship for a similar indication, which, if found, goes to confirm the assumption. But a single cast of the lead is not to be relied on, and casts may be taken every mile, say; that is, every six minutes if the speed is 10 knots. If these soundings as a whole conform to those on the chart in the neighbourhood of the point where the ship is supposed to be sailing, the supposition can be taken as correct.

At important places far more soundings have been made by the Hydrographical Department of the Admiralty than are, or can be, shown on the charts. On a chart the soundings cannot be less than $\frac{1}{6}$ of an inch apart, which is equivalent in nature to 100 yd. if the scale is 3 in. to the mile. The chart gives the depths at either end of these 100 yd., but no information as to what there is between; and it is the mariner's duty to avoid assuming that if he is safe *at* the soundings he is safe *between*. "Instead of considering a coast to be clear, unless it is known to be foul, the contrary should be assumed", say the Sailing Directions. But when the soundings are close together, closer than can be shown on the chart, and when reliance is placed on them, contours or isobaths are drawn on the chart according to a regular notation shown in a special sheet published by the Admiralty.

Tidal Information.—Tidal information includes "H. W., F. & C.", and the difference in level between "M. L. W. Sp." (mean low water of spring tides), and "H. W. Sp." and "H. W. Np." (high water of spring tides, and high water of neap tides) for ports and harbours. Arrows in channels and bays show the direction of flow of flood and ebb currents, against which are often written the velocity of the currents in knots. In many places also the interval

of time between the occurrence of high and low water inshore, and the beginning of the tidal currents in the channels offshore is noted.

Lights.—All lights and beacons placed on prominent and dangerous places ashore, or on rocks, are shown. Lights must not be looked for on all such places. It is rather planned to place sufficient to enable the sailor to locate his ship, so that he may know where other dangers lie, and avoid them, and so that he may set or correct his course by them. Lights and beacons are often used as fixed points from which the position of the ship may be resected by means of sextant and station pointer.

If a light is only seen within a certain area, this "sector" is shown on the chart. Some lights show one colour, white, for instance, to a ship in certain positions, and another, red, for example, in other and possibly dangerous positions; these colour sectors are also shown and labelled on the chart. Sometimes natural features obscure a light inshore of a given line, and if so, this also is indicated, because it provides a useful guide in coastwise sailing.

Lights are of two main sorts: watched and unwatched. The former class includes lighthouses and lightships, the latter beacons with tanks for gas, which are replenished perhaps once in three or six months. The nature of lights is indicated by a special set of conventional signs. We cannot enter into the optical principles on which lights are constructed. They are directed towards making the light as steady and powerful as the circumstances demand, concentrating the beam so as to make it most useful; i.e. into a horizontal plane, in order that it may appear brightest as seen at sea, from sea-level, and at some distance. It is important that lights should be easily distin-

guished at night. Hence each light has distinctive characters, and two lights with characters not quite different at a glance are never erected, except at great distances from each other. Coloured lights are not used more than is necessary, and, if possible, only when they do not require to be seen from a great distance, because the colour screen cuts down the intensity of the beam seriously, the light from the same burner being reduced to half by a red screen, to quarter by a green. For purposes of distinction then, lights may be coloured or uncoloured, the colour being indicated by a contraction. They may be steady or fixed, revolving, flashing, occulting. Fixed lights burn steady, and are constantly visible. Revolving lights sweep the horizon; to the sailor their light seems to gradually grow brighter as the beam swings towards him, becomes dazzling as it strikes him, and wanes as it sweeps away till, for a space, it is no longer visible. The term "flashing" is self-explanatory. Occulting means that the light disappears for an instant; it gives a "flash of darkness". Flashes and occultations are arranged in sets or groups, for distinction, in the case of some lights; such lights are group-flashing, or group-occulting. Thus, on the chart mentioned above (Irish Channel), the light on St. Bees Head has "Lt. occ. ev. ½ min."—the light is eclipsed, or invisible for a moment every half minute; that on the Mull of Galloway, "Lt. occ. vis. ¼ min., and eclipsed for 7½ sec."—the light is occulting, disappearing every quarter minute for 7½ seconds; that on the Mull of Cantyre, "Lt. grp. fl. ev. 30 sec."—the light is a group-flashing one, a set of flashes appearing every half minute, the light being darkened between. No one of these lights in the same neighbourhood could be mistaken for another. The

height of the light (that is, of the lantern) above sea-level is also given. This is valuable, because by taking the angular height of the light above him the sailor can tell his distance from it. The range of visibility, the distance from which, on an ordinary clear night, the light would be visible to a man standing on a deck 15 ft. above the sea, is also given. This is useful for identification purposes, and for indicating the position of the ship when the light comes into view; but lights can often be seen much beyond their range, a first-class light being able to be picked up by its "glow" even when it is below the horizon, while even a faint haze may cut down ranges of visibility considerably, and a fog may make the brightest light insignificant.

Buoys.—Buoys are floating marks moored to indicate channels and fairways, and to point out dangers. They are distinguished by make, shape, and colour, all being distinguished on the chart by contractions. Spar buoys are masts erected on floats, such as casks, which are ballasted to keep the masts upright, and anchored. The other types require no description. Buoys may carry "beacons", erections on top of them, not necessarily luminous. These beacons are usually dark-coloured, never parti-coloured, and consist of a pillar or a staff carrying a globe, cage, diamond, or triangle. Certain colours are reserved for definite purposes; thus green buoys are only used to mark obstructions which are not natural—wrecks, green buoys carrying the word "Wreck" in white; submarine telegraph cables, similar buoys lettered "Telegraph"; mine-fields, outlined by buoys chequered green and white. Spherical buoys are kept for banks, striped buoys for banks and shallow places in harbours and anchorages. Channels are buoyed so

that a ship approaching harbour, or, if the channel is not the fairway to a harbour or inlet, sailing with the current of flood tide, is safe if she has to starboard (right-hand side) conical buoys painted a single colour, often red, sometimes carrying a staff with a globe on it (staff and globe); to port, can or cylindrical buoys (i.e. showing a flat top above water), of a colour different from those to starboard, often black, sometimes with staff and cage. Mooring buoys, which usually show the round side of a cylinder above water, are not shown on charts.

Fog.—Fog is the worst of the sailor's troubles, and fog signals are associated with lights and buoys. They are sirens, whistles, bells, explosive signals, and their nature, together with their distinctive characters, if any, are indicated by obvious contractions on the chart.

Safe Courses.—Certain indications of safe courses in dangerous places are given on charts. These are often by "leading lines". Two prominent marks are selected, called leading marks. If the ship keeps these in line she is on the leading line. The marginal sketches referred to above are of great use to the sailor in picking up these marks. Several instances will be found on the Irish Channel chart mentioned; for example, north-east of Dundrum Bay is a line labelled "Ringford Pt., open of Guns I., clears all the shoals", which means that if the ship follows a line so that Ringford Point is visible outside of and beyond Guns Island she will avoid all the shoals obstructing the way into the bay from that direction.

Fig. 90 is not an actual copy of a chart, but a simplified sketch to illustrate the appearance of one without the confusing abundance of detail of the actual thing. It should be studied in connection with

the table of symbols, and then the chart of the Irish Channel (any other more easily obtainable will do as well) should be obtained and gone over carefully by the student. He must remember that while there is considerable uniformity in the charts of all nations, the descriptions given here refer to British Admiralty charts, and small differences must be expected in others.

CHAPTER VII

CLIMATE AND WEATHER

The Atmosphere.—Air is a mixture of gases, chief among which are nitrogen, oxygen (by far the most abundant), and carbon dioxide in very small but very constant and important amount. There are also rarer gases. It also contains a variable amount of water vapour, which does not behave as do these other gases, and complicates the behaviour of the air under varying conditions. Being material, air has weight, and though its density, or mass in unit volume, is very small, by reason of its weight it presses on the supporting surface of the earth at the rate of some 15 lb. per square inch. But, since the air is gaseous, this pressure acts not only downward on the earth, but in every direction, so that any given body of air presses "sideways" on every neighbouring body of air, and upward, supporting the column of air that lies above it. The pressure of the atmosphere is measured by means of the barometer, and varies from time to time at any given place, and from place to place at the same time. Air is compressible; the volume of any given amount of air depends on the pressure exerted upon it (or on the equal and opposite pressure it exerts). Reduce

the pressure and the air increases in volume in inverse proportion. In doing so, the air does work at the expense of the heat it holds, and becomes cooler; increase the pressure, and the air is reduced in volume in inverse proportion to the pressure, which does work in compressing the air, and that work appears as heat energy, so that the air becomes warmer. This is called *adiabatic*[1] heating and cooling of air, since no heat is added to, or abstracted from, the air. When air is heated, it expands in volume, and so decreases in density; when cooled, it contracts and becomes heavier. This behaviour of gases, under changing pressure and temperature, is summarized in Boyle's and Charles's Laws.

Effect of Change of Altitude.—As we ascend above sea-level there is less air above us, and therefore the pressure of the atmosphere is less. If the pressure at sea-level is equal to that of 30 in. of mercury in the barometer, at 900 ft. up the pressure has fallen to 29 in. With reduced pressure the density has become less, and to reduce the pressure another inch, to 28 in., it is necessary to ascend a further 930 ft., to 1830 ft. Pressure of 27, 26 . . . in. is not met till heights of 2790, 3790 . . . ft. are reached. At about 16,000 ft. the pressure is about half that at sea-level; half of the atmosphere is above, half below. At 7 miles up the pressure has fallen to $\frac{1}{4}$ that at sea-level, at $10\frac{1}{2}$ miles to $\frac{1}{8}$, and so on. Since pressure goes on decreasing in this way, it is not possible to say that the atmosphere ceases at any given height; but at the height of 30 miles the pressure is only about $\frac{1}{10}$ in., and conditions are very different from those at sea-level.

[1] Greek *a*, not; *dia*, through; *batos*, passable: impassable to heat, neither losing nor gaining heat.

From what has been said by the way, it will appear that heights can be estimated by reading the barometer at different altitudes, and applying what is called the *vertical barometric gradient*, the rate at which atmospheric pressure falls with altitude. But in order to secure good results, it is necessary to keep a barometer at the starting-point of the observations, and to have it read continuously, in order to allow for the natural variations of pressure with time (cp. Chapter IV, p. 136).

As there is a pressure gradient falling with height, so there is also a falling temperature gradient in the atmosphere as we ascend. If the air is "dry", the rate is about 1° F. for 300 ft. near sea-level, but it varies very much from place to place, is greatly affected by the amount of water vapour in the air, and increases at greater altitudes up to about 10,000 ft. Above this, the gradient is nearly constant at some 1° F. in 300 ft. till a height of 40,000 or 50,000 ft., or 7 to 9 miles, is reached, when the temperature is constant all over the earth at about – 70° F. Higher up there is either no gradient, or a very slight reversed gradient, the temperature rising with altitude. This topmost layer of air is called the *stratosphere* or *isothermal layer*, and its discovery is comparatively modern. The changes and motions of the atmosphere that bring about the vicissitudes of weather take place below it, though it is not without important influence in determining them.

Changes in the Atmosphere.—Changes of weather are associated with changes in the atmosphere. They are in common experience associated with winds and changes of wind, or movement in the air. We must seek the key to them in the causes that give rise to and control winds.

Isobaric Surfaces.—Let us imagine the earth as the

smooth ball we considered in the earlier chapters. If the air is at rest, there will be a definite rate of fall in pressure of the atmosphere with increased altitude; but at all points at the same altitude the pressure will be the same. We can think of the atmosphere as subdivided by imaginary shells, concentric with the earth, such that the atmospheric pressure on the surface of any one of them is uniform. Such surfaces are called *isobaric surfaces*. Clearly, digressing for a moment to the actual surface of the earth, these surfaces will intersect the surface of the earth in contour lines, the isobaric surface of 29 in. (30 in. being the sea-level pressure) cutting the 900-ft. contour line, that of 28 in. the 2000-ft. contour roughly, and so on. The lines in which isobaric surfaces intersect the earth are called *isobars*. If, however, the pressure at two near-by points at the same height is not the same, these pressures opposing one another horizontally, as we have pointed out, the higher will prevail against the lower, and air will be caused to move from the region of higher pressure to that of lower. Such differences of pressure at the same altitude exist, and in them we find the cause of winds. When they exist the isobaric surfaces are no longer spherical. They are warped, being lower where the pressure is lower, and domed upward at places where the pressure is higher. Similarly actual isobars do not follow contour lines.

It is not easy to construct the isobaric surfaces at any time; to do so it would be necessary to observe the pressure at different altitudes at many places. Only at a few is this done at present by means of small "pilot" balloons, carrying instruments which keep automatically a continuous register of pressure, temperature, and other phenomena. But pressure is

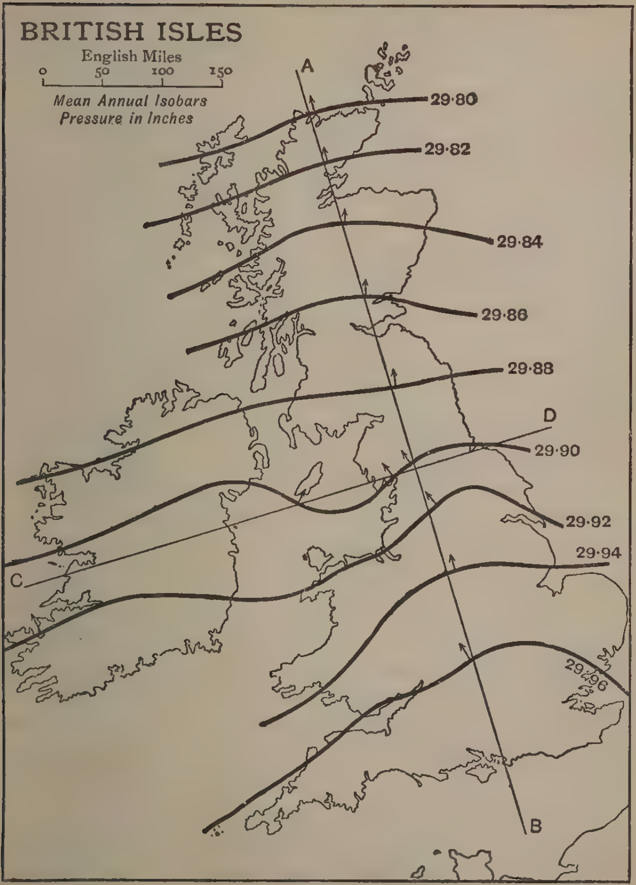

Fig. 93.—Mean Annual Isobars: pressure in inches

observed at many places, meteorological stations, on the surface of the earth, and it is easy to draw the surface isobars approximately from the observations.

On a map the figures for the pressure at each station are written against the position of the station, and the isobars are sketched in by estimation, much as we saw is done in the case of contour or form lines. The closer the stations the more certain the isobars. At present, with the number of stations available, even in well-settled countries like our own, it is only possible to obtain a general idea of the distribution of pressure. What we wish these isobars to represent is the *horizontal pressure gradient*, i.e. the rate at which pressure varies with distance in any direction at the earth's surface.[1] The stations are at different levels, some near sea-level, others on high ground. There is a natural difference of pressure on account of the difference of altitude, and, in order to obtain an idea of *horizontal* differences of pressure at a point, we must eliminate this. Therefore the ordinary vertical pressure gradient is applied as a correction to give the pressure that would correspond at sea-level to the pressure at each point. Say the pressure on Ben Nevis, which is 4406 ft. above sea-level, is 24·47 in., the pressure at sea-level would be 1 in. higher for every 900 ft. of altitude. The "correction to sea-level" is therefore + 4·89 in., and the pressure plotted on the map is 29·36 in. Thus, the isobars drawn on the map are the lines in which the actual isobaric surfaces cut the imaginary smooth spherical earth. Figs. 94, 95 show the form of the isobaric surfaces along the lines AB, CD, on fig. 93, and the manner of its construction from that figure is easy to follow. The direction of the winds, blowing from high-pressure to low-

[1] The student should bear in mind the analogy of contour lines, which, in the flat, indicate differences of level, and therefore slopes. The isobars similarly indicate "pressure slopes", down which winds tend to blow; and, as the line of steepest slope crosses the contour at right angles at each point, so the line of steepest pressure-slope crosses the isobars at right angles. Water tends to flow along these stream lines on the earth, air to "blow" along the similar lines with reference to the isobars.

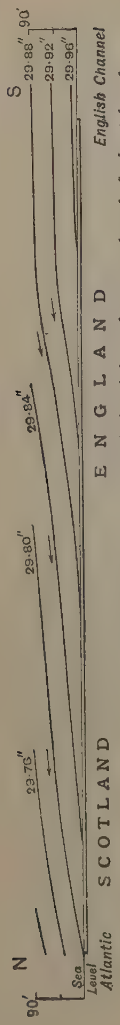

Fig. 94.—Section of the lower 90 ft. of air along AB, fig. 93. The vertical scale is much greater than the horizontal, and very greatly exaggerates the slopes of the isobaric surfaces

pressure, is shown on both by means of arrows.

Now, what sets up differences of pressure? Clearly, since pressure depends on the weight of the air, and weight depends on density, what alters density will alter pressure, and warming the air diminishes its density. We shall, therefore, proceed to examine the question of the warming of air. The warming agency is, of course, the sun.

Radiant Energy.—From the sun there emanates in every direction what is called *radiant energy*, and a small portion of this energy is intercepted by the earth. On the earth it becomes apparent to our senses as light and heat, and, less obviously, as the cause of certain chemical and electrical effects. This energy is not itself heat or light;

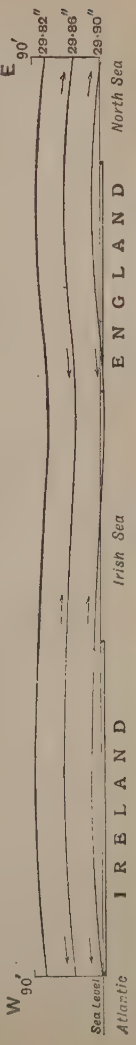

Fig. 95.—Section of the lower 90 ft. of air along CD, fig. 93, to show the warping of the isobaric surfaces over the British Isles

it is energy (which manifests itself very variously), the power of doing work, and it is radiant, because it passes through space from its source. It behaves, to the best of our knowledge, as though it passed through space as an oscillation of material particles, as wave motion. Hence it is convenient to assume that it is so, and to assume that there is a material, or medium, whose particles convey it. This imaginary medium is called *ether*. All we know of it is, first and most important, that it has the property of conducting radiant energy, and second that it is too light to be apparent to us, and permeates ordinary matter, for example, transparent bodies.

These undulations or waves are of length varying over a wide range, but radiant energy travels uniformly at the velocity of light. Their effects differ according to the wave-length. Those of greater length, when they fall on matter, warm it, and are called heat or thermal waves. Of shorter length are the waves which produce the phenomena of light, but there are waves of still shorter wave-length. When these waves encounter any body, they may pass through more or less completely, or they may be chiefly stopped or absorbed, or they may be turned back or reflected to a greater or less degree. The absorption of the "dark" heat-waves chiefly interests us. Dark-coloured surfaces absorb radiation more readily than light-coloured ones, and rough surfaces more readily than smooth. Hence dark roads, roofs, rocks warm up rapidly in the sunshine, while light-coloured or smooth surfaces, like those of water, bright metal, glass, remain cool. Bodies, having absorbed radiant energy, proceed to emit it again, the wave-length being increased. Thus, the earth, absorbing radiant energy from the sun, radiates it again, entirely as dark rays of long wave-

length. Surfaces which readily absorb, also readily radiate. Hence the land surface heats up more rapidly than the sea under the daytime sun, and also cools more rapidly during the night.

Insolation.—Air, water, and the rocky material of the earth's surface behave differently towards solar radiation, or, as it is called, **insolation.** Water takes more heat to warm it by a given amount than anything else known. Its "specific heat" is high. The material of the earth's crust has a much lower specific heat, and air a still lower. Again, when water is warmed it evaporates more readily, and a great deal of the heat absorbed goes to do the work of evaporation, and becomes "latent", instead of increasing the temperature of the water. This affects neither the crust of the earth nor the air, except in so far as certain parts of the crust are water-logged or marshy. When matter is warmed it expands, becoming less dense. In the case of mobile water and air, this leads to convection: currents of light, warm water or air rising, and cold ones flowing in to supply their room. This distributes the heat through the whole body of water or air. The solid earth, being rigid, is not affected in this way. Lastly, both air and water are transparent, and allow much of the radiation from the sun to pass through them. The earth presents two kinds of surface to solar rays, rock, including earth, and water; and the former heats up readily, the latter slowly, for the reasons given.

We are, however, more immediately concerned with the heating of the atmosphere, and air allows practically all the solar rays to pass through it unabsorbed. It is scarcely heated at all directly. The lowest layer, however, in immediate contact with the earth, is warmed by contact with the warming surface of the

earth; and, warming, becomes lighter, and floats up through the cooler air above it. The air over the sea, which remains cool, is not warmed in this way, and in the neighbourhood of the land it flows in as a sea breeze to take the place which would be left vacant by the ascending warm air over the land. The air, rising, passes into regions of less and less pressure, and expands, cooling adiabatically. This cooling is at the rate of 1° F. for every 180 ft. or so of rise, which is less than the normal vertical temperature gradient; and, in consequence, the air rises to considerable heights, warming by contact the air through which it passes It may be mentioned that in the lower layers of the atmosphere there are considerable amounts of solid matter in the form of dust, which directly absorb solar radiant energy and warm the air in contact with them, and that they are more abundant, for obvious reasons, over the land than over the sea, and lower in the air than higher.

Warping of Isobaric Surfaces by Insolation.—Let us now consider the case of a low island in the middle of the ocean. Imagine the atmosphere above it and the neighbouring sea divided into layers by isobaric surfaces parallel to the surface of the earth, and the column of air above the island isolated by an imaginary vertical boundary. A vertical section of this is shown in fig. 96. The atmosphere will be quite still over land and sea. Now, let the sun shine brightly on the scene. The lowest layer of air over the island, say that below the isobaric surface of 29 in. (pressure at sea-level 30 in.), will be warmed by contact with the land, and will expand, pushing up, as it were, the other isobaric surfaces. But this pushing up takes time, and at first the isobaric surfaces above a certain height will be crushed or crowded, so to speak, by

those below them. This state of matters is shown in fig. 97, the isobaric surfaces above that of 28 in. being crowded. For the sake of simplicity and clearness,

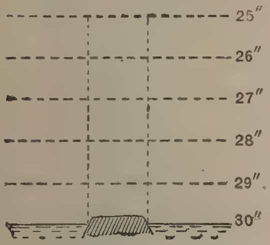

Fig. 96.—Air at Rest

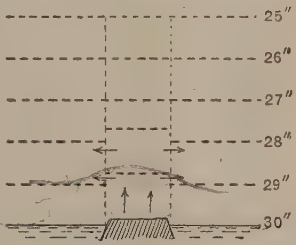

Fig. 97.—Air at rest high up; blowing outward lower down; rising at surface of earth

we shall take it that the pushing up is confined within our imaginary vertical boundary. It is clear that, as in the figure, while at sea-level the pressure is still 30 in. on land and sea, at some height above it the pressure is greater over the island than beyond it. Hence, upper winds blow outward, as shown by the arrows. But on account of the passage outward of air, there

Fig. 98.—Air at rest high up; a cyclone in lower air completely established; convection currents in lower air

is now less over the island than over the adjacent sea, and hence the pressure becomes less at and near sea-level within the boundary than without. Therefore in-blowing air-currents are set up at low levels, and the in-blowing air is warmed by the warm island, expands, and keeps the process going as long as the sun shines sufficiently. This final "steady state" of

matters is represented in fig. 98, in which, since the horizontal change of pressure is never in nature abrupt as in the artificial conditions of fig. 97, the isobaric surfaces are shown gently bent instead of "kinked". From this case we have seen that over warm surfaces we find at sea-level low atmospheric pressure as compared with the higher pressure obtaining over adjacent colder surfaces.

The warming of the lower layers of air, in causing them to expand, lowers their density, so that they tend to float upward through the colder, heavier air about them. As the air blows in at low levels, therefore, it rises over the island, room being made for it by the outward movement of air aloft. But as the air rises it expands, cooling adiabatically, and its temperature falls more rapidly than that of the air about it falls on the ordinary vertical temperature gradient. Eventually therefore it reaches a level where it is no longer warmer than the surrounding air, and there it ceases to rise. Beyond the circuit of the island, again, the air which blows inward below makes room for that which blows outward higher up; but this entails a downward flow of air. The space above the island is restricted, and the vertical air-motion is quite definite, but beyond it there is no limit to the area over which air may descend, and there is only a general settling downward hard to demonstrate in operation. All these movements, each of which is dependent on the others, constitute a circulation in the lower part of the atmosphere, and the general state of matters is denoted by the term *cyclone*.

Warming of the Earth.—Pass now to the general warming of the surface of the earth under the sun's rays, and the resulting distribution of pressure and winds on the earth as a whole. In proceeding to

do so we shall not at first take into account the variation of land and sea surfaces, but regard the

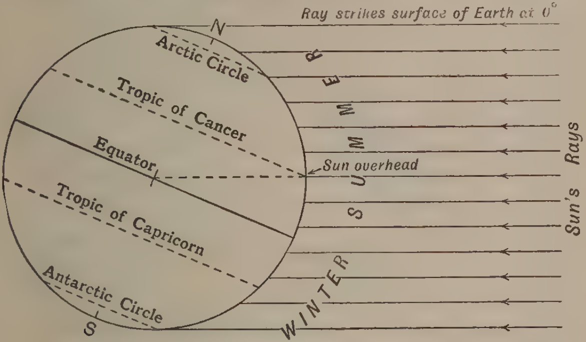

Fig. 99.—Distribution of insolation over earth at June Solstice

globe as though it were land entirely. The sun's rays, as we have seen earlier, are to be regarded as parallel, but on account of the curvature of the earth,

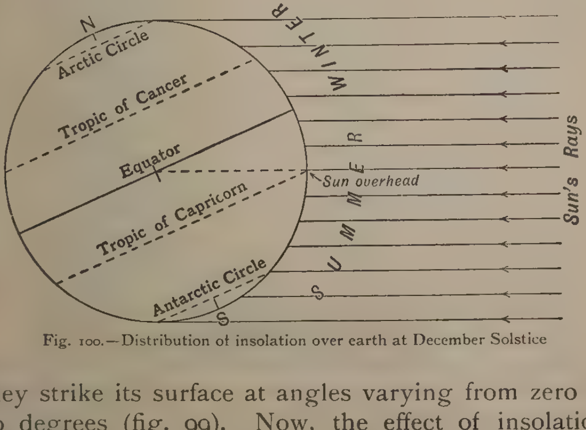

Fig. 100.—Distribution of insolation over earth at December Solstice

they strike its surface at angles varying from zero to 90 degrees (fig. 99). Now, the effect of insolation depends on the angle at which it is received on the

earth. Take a piece of card of some size to serve as a screen. Mark out about the middle of it a square of 1 in. side, and cut out the square. Take a second card, and draw on it also an inch-square, and near one side of the card rule a line parallel to one side of the square. Stick a pin into the edge of the card at each end, and along the direction, of the line, so that, the pins being rested on a support, the card will turn about them as about a hinge. Now, on a sunny day, fix the screen as nearly as you can judge at right angles to the sun's rays. The other card place a foot or so below it, the pins resting on supports, such as a box or a pile of books, and the two cards being parallel. If the cards are truly at right angles to the sun's rays a square sunbeam, passing through the upper, can, by adjusting the position of the lower card, be made to illumine completely the square of an inch side drawn on the lower. If now the lower card be swung round the hinge the bright square will stretch into a rectangle, one side still an inch long, the other longer. Thus the sunbeam is received on the least area when the card is at right angles to the sun's rays, and the greater the inclination of the card to the sunbeam, the greater the area over which the radiant energy of the sunbeam is dispersed. Clearly the effect of the sun in heating any area on the earth is greatest when the area is at right angles to the rays of the sun, and less when the rays strike the earth at a lower angle, that is, when the altitude of the sun is less than 90 degrees (cp. fig. 101)

Winter and Summer Temperature.—The cause of the varying temperature throughout the year is the alteration of the altitude of the sun, brought about by the inclination of the earth's axis to the plane of the

ecliptic. The distance from the earth to the sun has very little to do with the matter. As a matter of fact, on midsummer day in the northern hemisphere the distance between earth and sun is at its greatest, while on midwinter day it is least. Fig. 99 shows the relation of the earth to the rays of the sun on midsummer day, fig. 100 the same for midwinter day. At these two times the greatest heating takes place at the tropics, $23\frac{1}{2}°$ N. and S. respectively. At the equinoxes the greatest intensity of heating is at the equator. The best way to visualize this is to imagine the rays of the sun in figs. 99, 100, shining

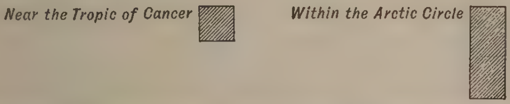

Fig. 101.—Average Area warmed by sunbeams of the same size at June 21

at right angles on to the paper, and so reaching both poles. From this we see also that the hottest belt of the earth swings throughout the year between the tropics, following the sun, and that the tropics bound what is on the average the warmest zone. The coldest region we expect to be in the neighbourhood of the poles. Thus we arrive at the old artificial division of the earth into climatic zones, two frigid, bounded towards the equator by the Arctic and Antarctic Circles, two temperate, extending from these circles to the Tropics of Cancer and Capricorn respectively, and one torrid, lying between the tropics.

Now, we have learned to associate low surface pressure, in-blowing surface winds, and out-blowing winds aloft, with relatively warm regions; ascending currents of air with warm regions, descending with cold. So we should expect to find the circulation of the atmos-

phere, as shown in fig. 102, a complete system in each hemisphere. But, since the amount of air on the earth remains the same, it is reasonable to assume that: (1) the amount of air moving towards the equator at the surface of the earth is the same as the amount moving polewards higher up; (2) the amount of air descending towards the poles is the same as the

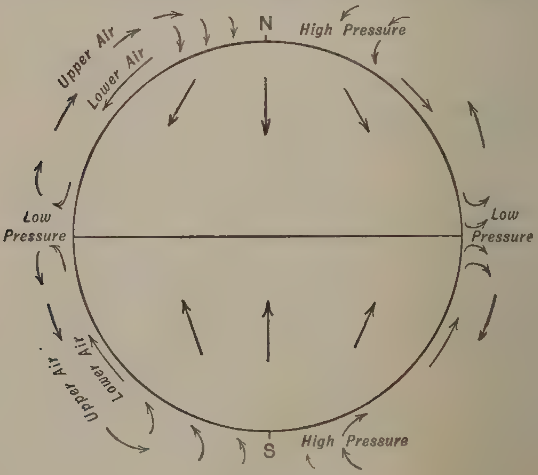

Fig. 102

amount ascending towards the equator. It is also clear that the winds blowing across the rough surface of the earth are far more impeded by friction than the winds of the upper atmosphere which blow over the surface of the layer of air immediately below. Further, in the 20 degrees of latitude nearest the pole the area is much less than in the 20 degrees nearest the equator. Thus, the upper winds are blowing into a smaller space, and so, to get their due amount of air carried, they must blow more violently. The

upper winds, therefore, and the winds blowing in high latitudes are more violent than those nearer the equator. The parallels of 30° N. and S. divide the hemispheres into two parts of equal area; it is not unreasonable to assume that ascending air occupies roughly the region equatorwards of these parallels, descending air that polewards.

General Distribution of Pressure and Wind.—As a matter of fact, the general distribution of pressure, and the general direction of the winds on the surface of the earth are less simple than those at which we have arrived. This is due in part to the facts mentioned in last paragraph, in part to the rotation of the earth. Particles of air moving in winds are like other bodies moving on the earth; not only have they their own proper motion, but they share in the movements of the earth as a whole. This question we cannot treat fully here, and any incomplete treatment of it is worse than useless. The student ought to look it up in the work in which Ferrel, who first solved it satisfactorily, presents it himself, his *Popular Treatise on the Winds*; it is obtainable in most good public libraries. Reliable information may also be obtained in the books mentioned below,[1] but the student is warned that in many books old and useless explanations are still current.

Quite generally, we may say, the highest atmospheric pressure is found along two belts round the earth. These lie rather polewards of the tropics, and the pressure is not uniform along them. They are usually called the *tropical high-pressure belts*. Both towards the poles, and towards the equator from these belts, pressure falls, and the lowest pressure on the

[1] H. N. Dickson, *Climate and Weather*; W. M. Davis, *Elementary Text-book of Meteorology*; P. Lake, *Physical Geography*.

earth also occurs along two belts, generally round the Arctic and Antarctic Circles. Beyond these circles atmospheric pressure rises towards the poles. The winds *tend* to blow from the belts of high towards those of low pressure, at right angles across the isobars (study the climatic maps in your atlas here). But actually they are modified according to Ferrel's Law, which states:

In the northern hemisphere winds blow as if they were turned to the *right* from the path at right angles to the isobars.

In the southern hemisphere winds blow as if they were turned to the *left* from the path at right angles to the isobars.

Hence follows Buys Ballot's Law: Stand with your back to the wind; in the northern hemisphere you will then have low pressure on your left, high on your right; in the southern hemisphere low pressure will be on your right, high on your left.

As a matter of fact, winds blow more nearly along than right across the isobars; very strong winds blow in a direction very little inclined to the isobars. A general scheme of the isobars and winds, together with the names of the winds, is given in fig. 103. These are such as would occur on the earth if there were no diversity of land and sea, and collectively they are known as the Planetary Circulation of the Atmosphere. The dweller in the northern temperate zone knows actual winds vary from this general scheme, which, nevertheless, can be seen clearly to represent the underlying plan of things. Some of the variations we can explain as due to movement of the tropical high-pressure belts north and south with the sun, the arrangement of the great land masses in the ocean, irregularities in the surface of the land, and,

especially, to the behaviour of the water vapour in the atmosphere; but many of them are not yet understood, and to this fact is due the faultiness of our weather forecasts.

As the warmest belt of the earth swings north and south with the sun, so do the equatorial belt of low

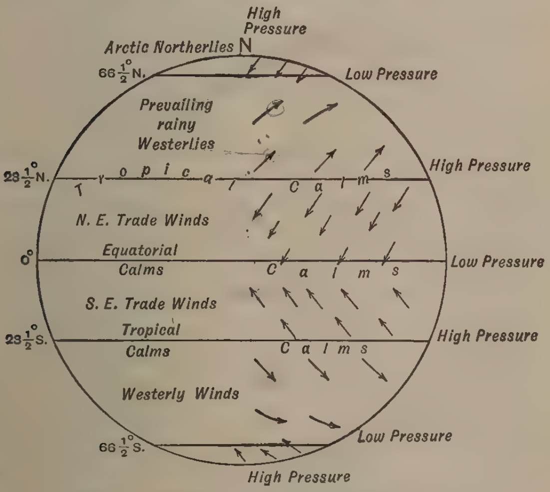

Fig. 103.—Surface Winds in the Planetary System

pressure and the tropical belts of high pressure. In the northern summer, therefore, the south-east trade winds blow north across the equator, and, being deflected to the right in consequence of their entry into the northern hemisphere, blow as south and south-westerly winds. The north-east trade winds blow over lands farther to the north, which during the winter are subject to prevailing westerly winds. In the northern winter exactly the reverse takes place. This is known as the *seasonal shifting of the pres-*

sure and wind belts, and has important consequences. (See pp. 209–211, and fig. 106.)

Still more important is the effect of the distribution of land and sea. In summer the land warms up rapidly, and over it pressure becomes less than over the adjacent sea. In the case of the smaller islands, the sea breezes set up daily in consequence tend to cool the land and prevent great accumulation of heat from day to day, and there is an alternation of afternoon sea breeze and morning land breeze. During the night the land rapidly cools, pressure over it becomes higher than over the neighbouring sea, which does not cool readily, and by morning the outward blowing breeze has set in. This alternation is well known on our coasts during very fine summer weather. But where there are extensive masses of land like that of Eurasia[1], things are very different. No tempering sea breeze of afternoon can penetrate its interior, and during the summer the heat goes on piling up from day to day, so that in some parts the surface of the land becomes excessively hot, and the air-pressure becomes relatively low. This state of matters is shown in fig. 104, the hot centre of low pressure being on the plateaux of Persia and Baluchistan. The isobars there are in the form of closed curves, and indicate a great cyclone, which will remain stationary all summer. Over the adjacent seas the isobars are also closed curves, but they enclose areas of greater and greater pressure, and indicate anti-cyclones. In the case of the cyclone, the winds form a great atmospheric eddy, whirling against the hands of a clock, since they blow in the northern hemisphere (cf. Australia). With respect to the land, the winds are on-shore, temper the heat on the margins

[1] A general name for the great continental land mass composed of Asia and Europe.

of the ocean, and bring rain. Inland they have already blown across a wide expanse of rapidly warming country, and are hot and parching. In the winter the reverse takes place. The land receives little warmth from the rays of the low-shining sun, and,

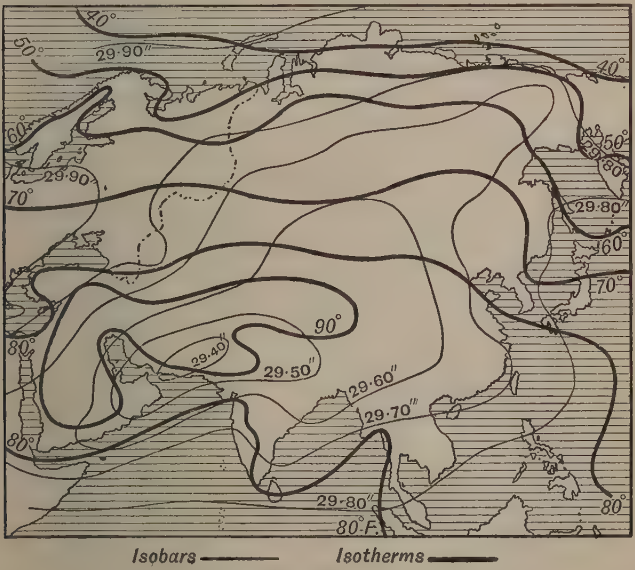

Fig. 104.—Asia, July Isobars and Isotherms. Pressure in inches; Temperature in degrees Fahrenheit

especially by night, radiates far more energy than it receives. Hence it becomes ever colder as the winter asserts itself, and centred in the icy north-east of Siberia is a high-pressure system or anticyclone, in which the gentle winds form a clock-wise whirl of out-blowing air-currents, which along the coast blow sea-ward. This seasonal alternation of winds is known as **a Monsoon.**

If the student looks in climatic maps in his atlas for the tropical belts of high-pressure, he will find them as a chain of anticyclones, their continuity broken by their passing from land to sea. They present a certain contrast in the two hemispheres, which he will have no difficulty in assigning to the contrast in the amount of land in each.

Water Vapour.—Water vapour is a constituent of the atmosphere, always present, but in very variable amount. At the surface of every sheet of water evaporation is continually going on, even when the weather is very cold; otherwise no laundry-maid would ever be able to get her washing dried outside in the air. The rate of evaporation or drying varies very much, and the two factors which (apart from wind) control it are the amount of water vapour already in the air, and the temperature of the air. Given a certain space, whether air-filled or not, at a given temperature, it will take up a definite amount of water vapour. When the space has taken up all the vapour it can, it is said to be **saturated.** If the temperature of the space rises, it can take up more water vapour, and if there is liquid water present, it will proceed to do so. When it can still take up more vapour, it is said to be **unsaturated.** If the temperature falls, the amount of water vapour that the space can accommodate decreases, and if it was saturated to begin with, some of the vapour will condense to the liquid form. If at first the space was not saturated, as the temperature falls a point will be reached at which the amount of vapour it contains will saturate it, and when this point is passed, condensation will begin. The temperature at which condensation of water vapour to liquid water takes place is called the *dew point.* Air over the sea tends to be saturated, air

over the land to be unsaturated. Warming air, even if saturated at first, gradually becomes more and more unsaturated, and promotes evaporation. Cooling air, even if unsaturated to begin, at length becomes saturated; and then the vapour in it condenses, and precipitation—that is, fall of water in liquid or solid form—eventually takes place.

A vapour is not a gas, and it does not obey the laws to which true gases conform: it is too near its point of condensation. For this reason the water vapour in the air is responsible for anomalies in the behaviour of the atmosphere, and consequently anomalies of weather. Normally we think of water passing into the state of vapour at the boiling-point—that is, at 212° F.—but only if heat continues to be applied. This additional heat supplies the energy which brings about the change; it disappears *as heat*, and is called the **latent heat of vaporization** of water. The amount of heat transformed in this way is very great—five times as much as is required to raise the temperature of the water from freezing-point to boiling-point. Evaporation in the atmosphere thus involves the disappearance as heat of a great deal of "heat energy". Obviously this is a powerful cause of the slow heating of the sea, and of the air over the sea. It must not be assumed that before the evaporation takes place the air and water become warmer than we find them, and then cool down as evaporation goes on: the radiant energy from the sun passes directly into the "potential" energy we call latent heat, in virtue of the work it does in separating the molecules of the liquid water into the state of the less crowded molecules of the vapour. The water having been evaporated, the vapour obviously becomes a vast reservoir of energy, which is tapped when condensation takes place, and

latent "heat" is liberated as heat. Let us look back to the case we considered above (p. 191), in which we learned of the ascending air-current over the actively warming surface of an island. As this air rises, it passes into regions of lower and lower pressure, and cools adiabatically. Cooling reduces the capacity of the air to contain water vapour. The rising air, if at first unsaturated, will eventually become saturated, and condensation will ensue. The latent heat is now "liberated", and goes to swell the energy sustaining the upward movement of the air,

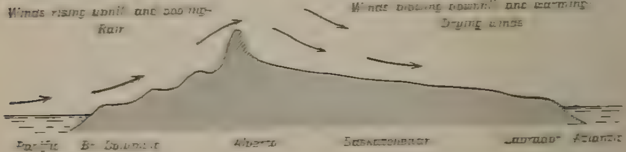

Fig. 105.—The Chinook Wind (cp. Föhn wind)

originated by the solar radiant energy. Even now, however, it does not appear as heat; rather it helps to promote the separation of the particles of the gas, i.e. the expansion; it tends to retard the adiabatic cooling of the air. When eventually this air comes into the region of descending currents, it will be carried down into regions of higher pressure, will be compressed, and the energy acquired from the condensed water will appear in the form of heat. This is clearly seen when the form of the land causes moist air to rise over mountains and part with its moisture by adiabatic cooling. The warm moist westerly winds which blow inland across the Canadian Rockies are thus forced to ascend and cool adiabatically (fig. 105). The mountain belt is a region of heavy rainfall, which is greatest just to leeward of the crest; because the air, started

on an upward path, sweeps beyond the end of the upgrade before it begins to descend. Descending, it sweeps along the eastern slope as the well-known *Chinook* wind, which is famous for its warmth, due to adiabatic warming and the appearance as heat of the latent heat of the moisture it carried from the sea. The Chinook is a drying wind, and gives a semi-arid climate to Western Alberta. But it melts the snows on the wheat country after the winter, and allows cultivation to begin earlier. The same effect is found in winds blowing north down the Swiss valleys, and it takes its name from the local name of the wind, the Föhn.

We shall now return to the climatic zones, and by outlining the actual condition of things gain some idea of the effect of the causes we have just been discussing in modifying the planetary climate. It will be necessary to begin by learning how the observations of weather are made, and how the climate is studied by means of them.

Weather Observations.—Temperature of the air is measured by thermometers placed in louvred cases or screens.[1] These screens are placed at the height of 4 ft. above the ground, in order to secure uniformity in the conditions under which the observations are made. The thermometers used are an ordinary one, a maximum and a minimum (in order to record the highest and lowest temperature attained in the day, or part of the day), and a wet bulb thermometer, which

[1] A thermometer exposed to bright sunshine shows a high temperature, because it absorbs directly solar radiation. If under the same circumstances the same thermometer is tied to a string and whirled round the head for a few moments, it will read much lower; it will show the temperature of the air through which it has been passing. Thermometers are required in meteorology to give the air temperature. Hence they are sheltered from the direct rays of the sun in a screen to which air has free access. Kept so, they give the *shade temperature*, which is very nearly the true air temperature. For very exact work the "sling" thermometer is used, i.e. a thermometer whirled in the air, either by hand or mechanically. Wet bulb sling thermometers are also used.

always reads below the ordinary (or dry bulb) thermometer, on account of the supply of latent heat to the water which is evaporated from its surface. The farther the state of the air from saturation, the more rapid the evaporation, and hence the greater the difference between the readings of the thermometers. From this difference the dew-point, and hence the amount of moisture present in the air (expressed as a percentage of the amount required to saturate the air, and called the *relative humidity*) is calculated by means of tables. Pressure is measured by means of the barometer, the height of which above sea-level must be known. There is, of course, no need to keep the barometer in the screen with the thermometers. The direction and force of the wind are either estimated, or measured by means of an instrument called an *anemometer*. This may consist of a wind-vane for indicating the direction, and of a set of four cups at the ends of short arms whirling in a horizontal plane, a kind of windmill. The rate at which the cups revolve is indicated by means of a train of toothed wheels, and the relation of the speed of the cups to that of the wind is known for winds of different strengths. In other types of anemometer the wind velocity is measured by the pressure of the wind in an open tube, the mouth of which is kept facing the wind by means of a vane. The force of the wind is indicated by arbitrary numbers on the Beaufort scale (see appendix, pp. 304–5), or by the rate at which the air travels in miles per hour. If no wind-vane is available, the best means of determining the direction of the wind is observation of the direction of the drift of smoke. The "carry" of the clouds enables the direction and force of the winds of the upper air to be estimated; and since different types of cloud occur at different heights above the earth, several

air currents at different levels may sometimes be observed. The amount and nature of cloud in the sky is noted, and the amount of rain, snow, or other form of precipitation which falls each twenty-four hours. This is measured by means of a rain-gauge, which is simply a vessel whose circular mouth has a known area. The rain, or melted snow, collected in it is measured in a glass, graduated in accordance with the area of the mouth of the rain-gauge, to show the depth to which the rain fallen would cover the surface of the earth. Besides these personal observations, information is obtained from thermographs, hygrographs (instruments for indicating the relative humidity in the air by means of the property of hair, by which it alters its length as the humidity of the atmosphere varies), barographs, anemographs—instruments which, by clockwork or electricity or both, keep a continuous record of temperature, relative humidity, pressure, wind direction and force respectively. These recording instruments are liable to error, but they are checked by means of the observations made personally.

The observations are made at definite times at meteorological stations; every hour, or less frequently, according to the importance of the station. The temperature at a given moment of the day is not in itself of much importance; the general or mean temperature of a place is of much more moment, and this is arrived at approximately by taking the mean or average of all the observations made in the twenty-four hours. From these daily means are calculated yearly means, and means for pressure, humidity, rainfall, wind force are also taken. The relative lengths of time during which the wind blows from each direction throughout the year indicate the *prevailing wind*,

and the winds associated with different types of weather are tabulated. But years vary; sometimes, for instance, there is a remarkably warm year, sometimes a remarkably cold. Hence we find that the mean of the observations of temperature made at any place differs for different years. If, however, we have observations for a long period, cold years balance warm, and means for periods of, say, five years differ much less than yearly means. Means for longer periods of years vary still less, and eventually we arrive at a figure which is nearly constant, and is regarded as the mean annual temperature. The same thing applies to seasonal and monthly means; so we get mean winter and mean summer temperature, mean January, February, March . . . temperatures. Similarly there are rainfall, sunshine, cloud, and other means. These are *climatic elements*: they indicate the average condition of the weather; just as daily observations or the observations for any given month or year are meteorological, or *weather* elements. Weather changes; climate is not variable. It consists of a set of changes taking place in the course of the the year, but these changes are definite, regular, and recurrent.

If these average temperatures, pressures, &c., are plotted on a map, then lines can be drawn to pass through points where the mean temperature, pressure, rainfall are the same, just as contour lines are drawn (see p. 137). These lines are called isotherms, isobars, isohyets respectively, and serve to give a concise indication of climatic conditions. They are also drawn for seasonal and monthly means, and for single observations made simultaneously at many places; in the last case for the purpose of making weather forecasts. But, just as in the case of pressure

(see p. 182), so in that of temperature, there is a fall with elevation, and in order to have comparable data, it is necessary to reduce temperatures to sea-level. But in using isotherm charts one ought to bear this in mind; for the chart does not show actual or the mean of actual temperatures, but sea-level temperatures.

The Torrid Zone.—The chart of mean annual world-temperature in your atlas does not show the hottest part of the earth on the equator, but along a wavy line which lies mainly north of the equator. The imaginary line passing through the centre of the region of greatest temperature, bounded usually by the isotherm of 80° F., may be imagined to follow the hottest places on the earth, and is called the *heat equator*. Examination of similar charts for the hottest and coldest months of the year (July and January are usually taken as such) will show that the heat equator moves with, but not so far as, the sun, and that the hottest regions in these months are different. The reader who recalls what was said on p. 200 will have no difficulty in seeing that this is dependent on the position of the great land masses. The region of the heat equator is one of calms and active ascending air-currents which bring about copious rains; hence the dense equatorial forests, which reach their greatest development in the basins of the Congo and the Amazon. To the north and south of this equatorial belt are the regions of the trade winds. These winds blow day in and day out, and are so constant and steady that they controlled the navigation of sailing ships on ocean voyages before the days of steam. The belts which they cover change throughout the year, shifting north and south with the sun and the heat equator, as shown diagrammatically in

fig. 106. There is a fringe of the trade-wind belts which, during one part of the year, is subject to the

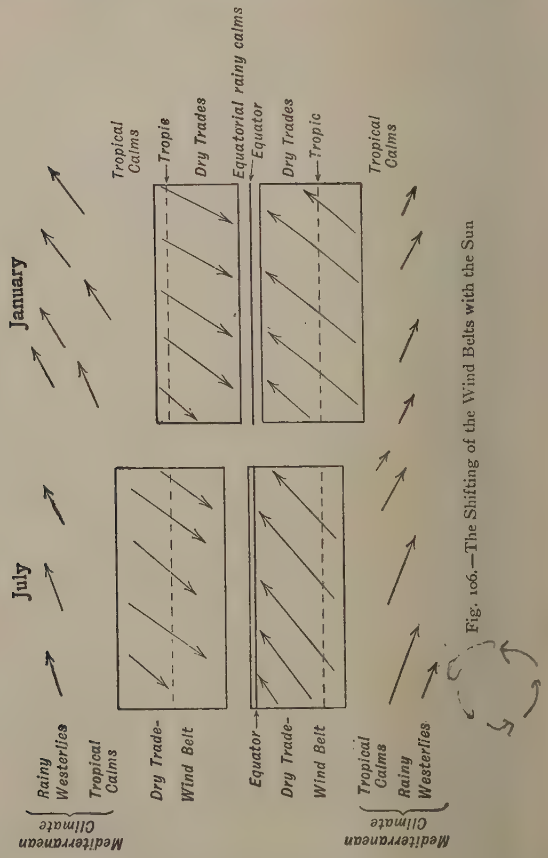

Fig. 106.—The Shifting of the Wind Belts with the Sun

Trades, during the other to the equatorial calms and rains. On the polewards skirt of the trade-wind belts is a region subject in summer to the Trades, in the

winter to the Westerlies. Now these trade winds blow from higher latitudes to lower, and therefore the air they carry warms up in its progress, and its capacity for holding moisture increases. They therefore tend to promote evaporation, and the Trades are dry winds. Their effect is best seen in the belt of desert which stretches from beyond Arabia across the Sahara to the sea. On the equatorwards side of the trade-wind belts, therefore, there is a region with a dry winter, due to the trade winds, and a wet summer, due to the equatorial rains. Further, since the heat equator moves twice in the year over places within the range of its swing, there are two wet seasons, or, as it is usually put, a double rainfall maximum in the year at these places.

Subtropical Regions.—The swing of the so-called tropical belts of high pressure with the sun gives a region of winter rains, due to the westerlies, and summer drought, due to the influence of the Trades. This state of matters is typically developed in the Mediterranean, and is often called the *Mediterranean type of climate*. Outside of the Mediterranean it is found in North and the tip of South America, at the Cape, and in the south-east corner of Australia.

Temperate Regions.—These may be taken to extend from the great high-pressure belts to the Polar Circles. They are of most importance to us, and their study is of greatest difficulty. They are occupied by the westerly winds, but these winds are not steady winds, blowing throughout the year like the Trades. Rather they are prevailing winds; that is, if the direction of the wind be noted every day throughout the year, it will be found that in the temperate regions many more days had winds from a westerly quarter than the number on which winds

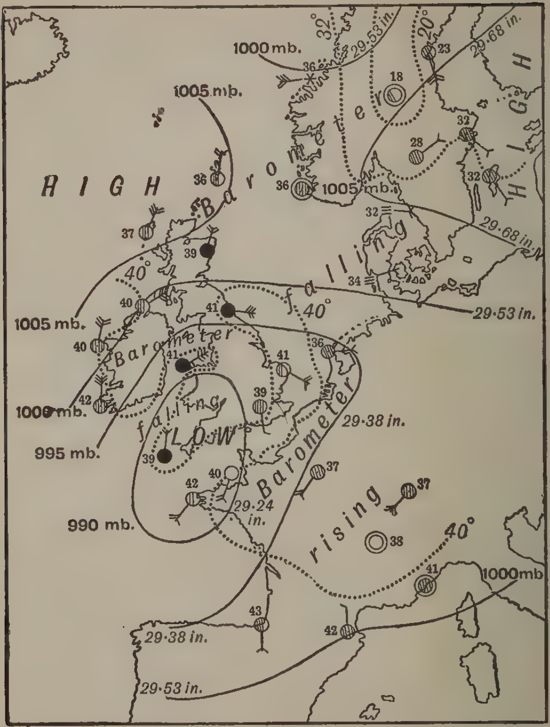

Fig. 107.—Synoptic Weather Chart for Wednesday, 1st March, 1916

EXPLANATION FOR FIGS. 107, 108, 111, 112, 113

Barometer: isobars ————, drawn for each 5 millibars.
[1 bar = normal atmospheric pressure
= 1000 millibars
= 29·53″
1 millibar = ·03″.]

Temperature: isotherms .... or ————, drawn for each 5° Fahrenheit.

Wind: shown by arrows flying with the wind; number of feathers corresponds with number on Beaufort scale:

⋙→ = wind of force 3 on Beaufort scale. Calm ○

Places where rain is falling ● Snow * Mist and fog ≡

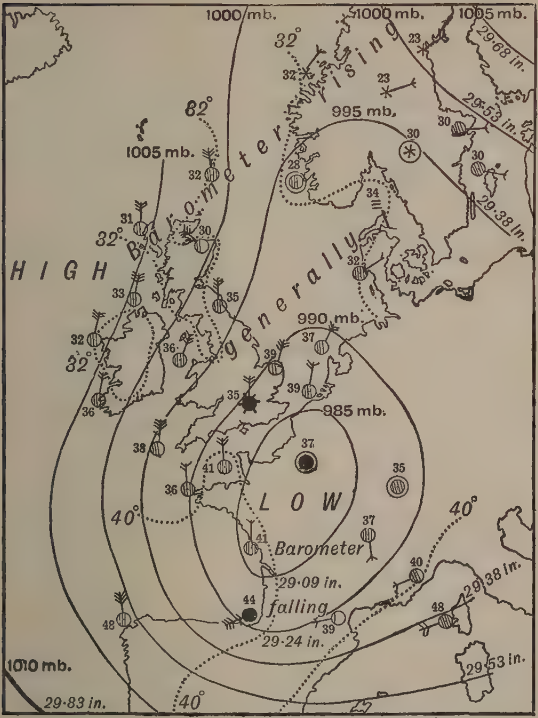

Fig. 108.—Synoptic Weather Chart for Friday, 3rd March, 1916

blew from other directions. As the winds are variable, so is the weather in general, and the causes of the one are the causes of the other. We have already learned what is meant by stationary cyclones, and what is the simplest and chief cause of them. The variability of weather conditions in the temperate zone, and particularly in the northern, is due to the passage of *moving* cyclones across them.

Stationary and Moving Cyclones.—A river in flood

flows along with numerous eddies, great and small, on account of the unevenness of its bed and the bends of its banks; and these eddies move down-stream with the current. In the region of the Westerlies the air flows on in a north-east or south-east direction as a whole, according to the hemisphere; but the general flow is diversified by eddies moving as a rule in the same direction, which, on the surface of the earth, appear as cyclones, or whirling storms. The isobars show the atmospheric conditions; they take the form

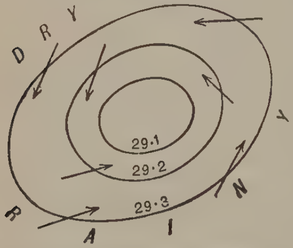

Fig. 109.—Pressure and Winds in Cyclone in N. Hemisphere

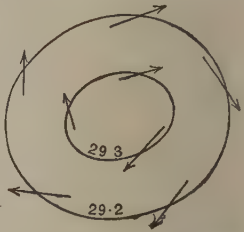

Fig. 110.—Pressure and Winds in Anticyclone in N. Hemisphere

of closed curves, often elliptical, but frequently of other and irregular shape, indicating pressure falling inwards. The condition one day may be that seen in fig. 107, the next that in fig. 108. The position and shape of the disturbance have changed, the whole having moved to the east. These storms move generally north-eastward in the northern hemisphere, the paths being diversified by minor vagaries, and the rate of movement being up to 30 miles an hour. The winds blow as in the case of a stationary cyclone in the same hemisphere; that is, inwards towards the centre of low pressure, but with a deflection to the right in the northern, and to the left in the southern hemisphere (fig. 109). In effect they constitute eddies,

whirling in the one case in the opposite, in the other in the same direction as the hands of a watch. The amount of the deflection depends on the strength of the wind, and that in turn depends on the horizontal barometric gradient. The winds may blow almost along the isobars, as near the centre of the violent cyclones, known as tornadoes, which are met in the Indian and China seas. There the winds are of extreme violence near the centre of the disturbance, and the navigator is therefore anxious to avoid the worst of their fury. Buys Ballot's law is of great value, therefore, to him in such waters. He can tell where the centre lies, and set his course to avoid it.

The weather of the North Atlantic is controlled by a succession of cyclones passing from south-west to north-east. They bring cloudy, wet weather. Naturally during the passage of a cyclone over any given part the rains are heaviest while the winds are from a south or west direction, partly because such winds pass from warm to colder regions, and their capacity for holding water vapour, at first high, is falling. In the northern hemisphere southerly winds blow in front, and northerly behind, the cyclone. As a cyclone approaches a place the weather is warm, muggy, and overcast, often wet. After it has passed, cool, refreshing weather occurs.

These cyclones, **depressions** or "**lows**", are classed according to the form taken by the isobars. The most important are the *V-shaped depression* and the *secondary cyclone*, terms which are common in our weather reports. In the former the isobars have the form of a V, the pressure falling towards the top of the V (fig. 111). The isobaric surfaces would form an inclined trough. The winds are much as in a cyclone, but most violent at the bottom of the trough,

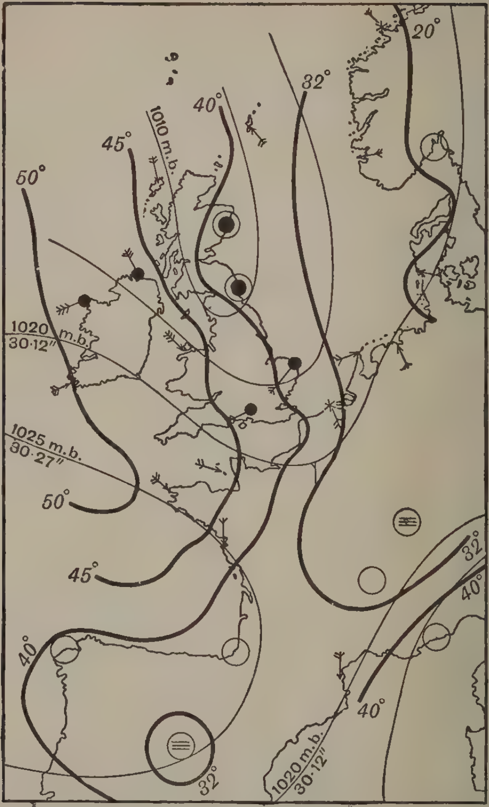

Fig. 111.—Synoptic Weather Chart, 21st December, 1915, showing V-shaped depression over British Isles; wedge of high pressure over the Bay of Biscay. Note the high winds associated with the depression, the very different direction of the winds to E. and W. of it, and the low temperatures on the E. compared with those on the W.—snow falling at Flushing and Christiansund.

where they form what is called a "line squall". As the bottom of the trough passes over a place, there is a sudden shift of the wind and rapid changes of the weather from clear to wet and cloudy. Line

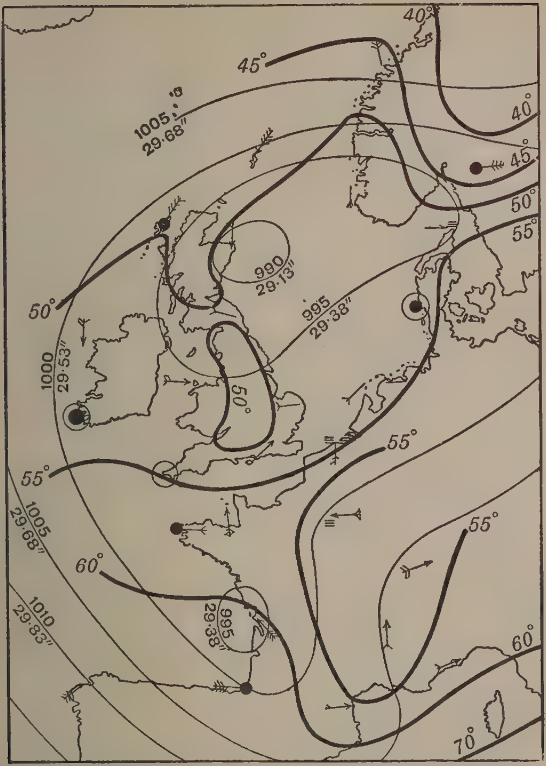

Fig. 112.—Synoptic Weather Chart, 26th September, 1915, showing secondary depression centred near the Gironde, France: principal depression centred near Aberdeen. Note the closeness of the isobars, showing steep barometric gradient, and strong winds at Stornoway and Lerwick; similar conditions on the S.W. of the secondary. Cp. conditions between the two centres.

squalls are very destructive to shipping. The secondary cyclone is a smaller depression on the skirt of a greater (fig. 112). Very often, if observing stations are widely scattered, secondary depressions are missed on pressure charts, for they are often quite small.

They may be indicated merely by a bending of the isobars (fig. 113), or by a separated closed isobar. Usually the pressure gradient is steep on the convex side of the bend, and violent, squally winds result. Gusty winds are characteristic of secondary depressions; these bring heavy showers which give place to a calm, determined downpour towards the centre. If the secondary be very small, such rains may be very local along a belt in the direction in which the disturbance is travelling.

Fig. 113.—Synoptic Weather Chart, 3rd January, 1915, showing secondary depression over the S.W. part of the English Channel (see bulge in isobars). Main depression centred to N.W. of Ireland. Note strong winds at Scilly and Channel Islands; also isobars close together and high wind at Stornoway.

Anticyclones. — The more or less ill-defined areas between the cyclones are anticyclones. An anticyclone is a region of relatively high pressure, as indicated in fig. 110. As a rule they give much weaker and more variable winds than cyclones, with clear skies sometimes, allowing free radiation to the earth when the sun's rays are nearly vertical, and giving hot days in summer; or in winter permitting the earth to radiate away its heat, and giving hard frosts. The clear frosty nights of early summer and autumn are associated with anticyclonic conditions; but just as often in our damp climate the rapid cooling of the surface of the earth reduces the moist air resting

upon it to the saturation point, and brings about fogs and thick weather.

The weather of western Europe is controlled by circumstances such as we have been describing. What exactly determines the formation of the continual train of cyclones is not clearly known. The more permanent pressure conditions are three: the tropical belt of high pressure, represented by a more or less permanent stationary anticyclone in the neighbourhood of the Azores; the polar ring of low pressure, represented by a permanent depression in the neighbourhood of Iceland; the Eurasian continental system, in winter an anticyclone, centred in the north-east of Siberia, in summer a cyclone, centred on the plateaux of Persia and Afghanistan. In summer the tropical high pressure intensifies and moves farther north, while the Iceland depression weakens and also edges northward. This reduces the northward pressure gradient, and winds are lighter, and storms are less frequent. In winter the Azores high pressure weakens and moves south, the Iceland low pressure intensifies and spreads farther south, high winds in our area and storms becoming in consequence more frequent.

Continual changes in these pressure systems are most effective, and make the weather the more uncertain, on the common margin where we live, and the incompleteness of our knowledge of the origin and nature of the moving cyclonic storms make the forecasting of weather all the more difficult. The only method available is that employed by the fisherman or village postman, to whom the state of the weather is a matter of personal importance, and who watches it through a long life and gets to know the signs of storm and fine weather sufficiently well to

gain some reputation for reliability. The scientific forecaster of the meteorological office only adds to his equipment the information obtained from the stations all over the country—which, being derived from measuring instruments, is more precise—and the long record of experience and exact observations kept during the life of the office. This is a point overlooked by those who expect the "weather clerk" to be infallible. His most constant guide is the isobar chart. Every day there is collected by telegraph, at the meteorological office in London, observations made all over the country at the same hour, and also many made on the Continent and on ships at sea. The barometric heights. reduced to sea-level, &c., are plotted on the map, and the isobars sketched in. The forecaster now sees at a glance what type of pressure system is over the country, and what is in the neighbourhood. It may be a cyclone, and yesterday's chart may have shown him a similar depression to the south-west of these islands. He says, therefore, "A depression is moving across the north of England . . . ", and proceeds to indicate for each district of the country the type of weather experience shows has been associated with a cyclone of this particular shape and position. The observing stations may be so situated as to give no indication of an important secondary depression. His forecast will be so much in error, and people will grumble and say the meteorological office is a waste of public money. To his chart he will add isotherms and symbols to indicate what the weather is at each station for, usually, 7 a.m., and some newspapers publish copies of this "synoptic chart" with their weather notes each day. Such a weather chart is given in fig. 108.

Commercial Importance of Climate and Weather.

—Climate determines very largely the desert and fertile regions of the earth, what areas carry forests (or would if they had not been cleared), and what will be grassy or steppe. It also limits the regions in which certain crops can be grown, and climate and weather are, therefore, very important in relation to commerce. Good weather forecasts are of great value. Wheat, for example, is grown in Australia and the western United States and Canada, in regions which are just too dry for it. Modern science has rendered this possible. For such regions a season just a very little drier than ordinary may spell ruin, and there it is of the utmost importance to have an early reliable forecast of the weather.

CHAPTER VIII

INLAND TRANSPORT: NATIONAL TRADE

Transport by Rail.—At the present moment the most important method of inland transport is by rail. The railway has the advantage of speed, reliability, and cheapness. There is a tendency to develop road transport by motor truck, because firms carrying on a large regular trade gain by having their transport in their own control, and lose nothing in cost, speed, or reliability; but this is in its infancy, and, while in a country like ours, where distances are short, it may become a serious rival to the railway, on the Continent and in North America, with their long runs, the latter is likely to hold its own for long hauls. One advantage which the railway possesses over road-borne traffic is its monopoly of its own roadway. On the public roads motor traffic must yield consideration

to other traffic, and loses some of the advantage of its speed.

It is sometimes stated that canal transport is cheaper than rail. This is a very misleading statement. In both cases the main cost is in the provision of the way. Ocean transport is cheap, very largely because there is no way to provide. Canal transport is only apparently cheap, because the canals have often been provided by the community, and are not run as paying concerns. Where canals have in modern times been constructed in the hope that they would pay, there has been disappointment. Even the much-praised canal systems of the Continent are failures financially, and the benefits they confer on the community at large are very doubtful if one put aside their purely strategic value, which cannot be estimated. The cost of constructing a canal is at least twice as much per mile as the cost of passenger railway lines, often four or even more times as much. Hence the proportion of freight charge in respect of capital outlay ought to be two to four times as much on canals as on railways. As a matter of fact the tolls usually fail to pay the annual charge for upkeep of the canals; and this is true of even such a conspicuous "success" as the Manchester Ship Canal. Sea transport is cheaper than inland. Only when the waterway is provided by a navigable river, which requires little in the way of regulation and improvement, is inland water transport cheaper than railway transport. We shall confine ourselves in this chapter to railway transport; but many of our conclusions, particularly as to the influence of topography on railways, apply with only rather less force to modern roads, and with greater force to canals.

Gradients.—The strength of the railway is in its

speed. Cut down the speed and you cut down efficiency. The locomotive works most economically when it runs at a more or less definite rapid rate; the falling off of the speed of a train on a long hill, and the laboured pounding of the engine as it crawls slowly upward greatly reduce efficiency. Its speed on the approach to a short hill will carry the train over the summit without much slackening, and without undue effort. Every cyclist is aware of the strain of climbing long hills. And in addition, the grinding of the driving wheels of the locomotive as it strains in the effort to start a heavy train on an upgrade is eloquent of costly wear on both rolling stock and permanent way. The hauling power of the engine may be beaten if the grade of the way is too steep. Thus the steepness of hills on railways is strictly limited: they are never more than 1 in 50 on first-class railroads, and an additional locomotive may be required to pull a train over sections with this slope. A slope of 1 in 25 is rarely heard of even on very primitive lines.

Railways are therefore very much affected by the relief of the country, and mountain barriers are very effective in keeping them out or in deflecting them. Quite slight elevations have great effects on the course of the railroads as may be seen in the map of Salisbury Plain (see Chapter V, p. 156) and in the maps to the west and north of it (cp. fig. 115). Comparison of the lines followed by rail and road on maps is very instructive in this respect, and the relations of railway and relief are so intimate that while contours show the chief points of topography, much more can be learned from the railways about the lesser features. Topography and trade are the chief causes which direct the course of the lines. Railways are only built where

there is trade to make them pay or where there is every probability of such trade arising in consequence of the advent of the line. Therein lies the cause of the difference in the history of railway development in new and old countries. In the latter the trade was already developed and localized before the railway was introduced, and the railways were built to connect the centres with each other and with neighbouring sources of raw materials of industry. In this country the railways were introduced as improved roads for horse-hauled coal traffic from pit to market, canal, river, or coast. The locomotive was developed later on account of the high cost of horse haulage due to the dearness of fodder in industrial districts. Thus the first railways were local, often of varying gauge. Trunk lines came later as their advantages were appreciated and the objections of the public to railway transport were overcome. Then for convenience of through traffic uniformity of gauge was introduced. The costs of construction were high, because the State insisted on a high standard of work for public safety, and on uniformity for strategic reasons; land was valuable because population was large, especially where railways were likely to be successful, and owners demanded high prices because the railway companies' need was urgent, and they were willing to pay; there were many vested interests and objections to be bought out and compensated; and, lastly, the State demanded that every scheme should be justified by its own merits on full and costly inquiry. In new countries like North America land was cheap, control less rigid, vested interests often non-existent, and the trunk lines were the pioneers of industry. The State made large gifts of land to the companies, because the extension of the railway

meant the extension of industry and settlement, and the extension of the control and authority of the State. Thus the cost of the United States railways was roughly four thousand million pounds against one and a quarter thousand million for those of the United Kingdom, whereas the length of road in the former is six times that in the latter; in other words a mile of line in this country cost on the average twice as much as a mile in the United States, in spite of the great cost of carrying the road across the difficult country of the Rockies. Our railways, in point of the original cost of the way, are about the dearest in the world.

Cost of Railway Construction.—The cost of construction of a railway depends on a number of things independent of the purely special considerations that have affected British railways, and by far the greatest item in original cost and upkeep is the permanent way. The chief factors are the nature of the country and the nature and amount of the traffic which may be expected. The primary influence of the nature of the country is exerted by relief, but the material and structure of the surface and underlying rocks have a secondary effect. Thus, the surface must be able to support the way with sufficient rigidity. A railway may require to traverse boggy or marshy country, and on the surface of a bog there is not sufficient support. The water-logged soil must be reinforced, and a solid foundation built up for the line. The surface of marshy country traversed by a railway may be felt by a foot-passenger to quake quite severely as a train passes.

In flat country the railway can choose its route straight from point to point. Minor irregularities can be filled up or cut down, the "spoil" from a cutting being used to build neighbouring embankments.

But if the country be cut up by watercourses, these must be bridged, and if the climate is moist, adequate drainage must be provided. In mountainous country the railway must climb to great heights. This it does by following the gentlest slopes. In the lower courses of valleys these are the valley bottom itself, but as the valley penetrates the mountains the slope steepens and gets beyond what is permissible for economical working. Then the railway follows the plan of the cyclist on steep hills: it climbs obliquely to the stream-lines, taking the long road. The problem in railway construction in such country is finding a long way up, or the longest horizontal equivalent for a given vertical height. The lowest passes in the mountains are sought by the railway, but the climb to them is often arduous. Narrow ridges may be tunnelled through, and so the extreme altitudes avoided. Spurs are usually rounded, but sometimes tunnelled, according to the circumstances of the case. Where the railway skirts steep hills a terrace must be cut spirally upward along the face of the incline. In a steep valley the railway may have to zig-zag from side to side, crossing perhaps on expensive viaducts; or it may climb on a series of hairpin bends. At the bend the line turns towards the slope, and to avoid steep grades extremely sharp bends must be taken. Now the sharpness of curves has an influence on speed, because the tendency for a train to leave the rails on curves is greater for the same speed on sharp bends than on open. Speed must be maintained, and the problem is to keep the bends sufficiently open. The railway engineer does not like curves of less radius than one mile. To keep his bends wide he may be forced to make tunnels in the flanks of the mountains, not to pierce through

them, but simply to secure open bends in avoiding extreme slopes. A good example of this occurs on the St. Gothard Railway (fig. 114).

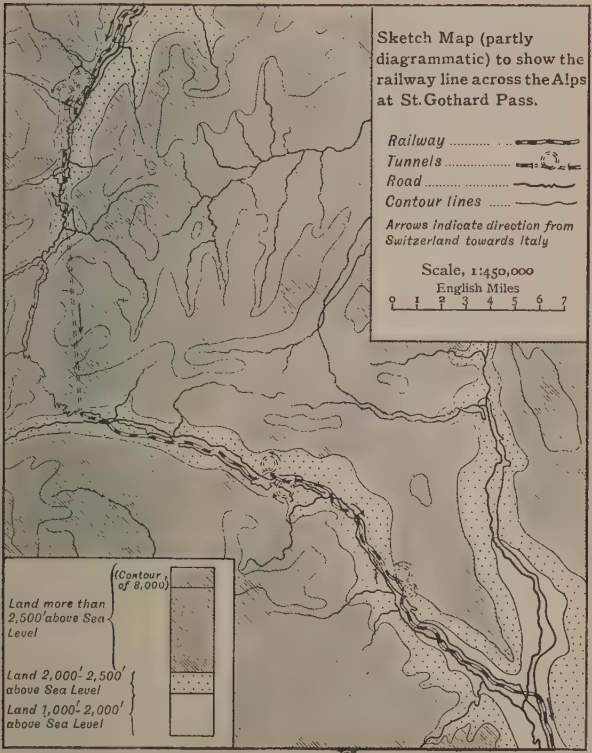

Fig. 114

The cost of deep excavations depends on the nature of the rocky material of the mountains, and contractors who have agreed to construct sections of railroads for a previously settled sum have not seldom

been made bankrupts because of their ignorance of the structure and general geology of the country they have had to deal with. Hard rocks are expensive to excavate, but they do not "cave in" when the excavations have been made. Soft, loose material may be costly to excavate because as it is removed more may flow in to fill up the excavation. Tunnels through such material must be lined with masonry or steel work, and cuttings must be banked. If a country requires many embankments, or if many bogs must be "bottomed" and there are few cuttings from which filling material may be obtained, the infillings may have to be carried a long way or obtained from special excavations near by which will serve no other use.

Traffic.—As to the nature and volume of the traffic, freight traffic does not require the smooth running necessary for passenger traffic, and the railway may be less substantially built. If the volume of traffic is small, vehicles of small capacity running on a narrow-gauge line may be sufficient. The British "standard" gauge is adapted for use by vehicles the distance between the flanges of whose wheels is 4 ft. $8\frac{1}{2}$ in. This suffices for the carriage of the heavy traffic in goods and passengers, and for the high speeds which obtain in a settled and thickly populated country like the United Kingdom. The gauge was adapted from that of horse-drawn vehicles, because many railways were first constructed for horse-drawn traffic. It is interesting to note that in many lands and in many ages the gauge for such vehicles has been wonderfully uniform; and it may be taken that on the evidence of practical experience this gauge is on the whole the most satisfactory. But in new, thinly peopled countries the volume of traffic will

be smaller, lower speed of travel will be obtainable on the revenue, and less costly narrow gauges will be sufficient. Thus the West Australian, New Zealand, Tasmanian, and Cape railways, and the Japanese railways have 3 ft. 6 in. or metre gauges. On these narrow lines bridges and tunnels are smaller and much less expensive. When traffic is small, single lines, built with short double lengths at intervals, so that trains may pass each other, are sufficient. The railways of the north of Scotland are single track. But where trains are frequent an "up" and a "down" track must be provided to avoid dislocation and delay, and on very busy lines, like that from London to Birmingham, four sets of metals are required to cope with the volume of traffic. Only heavy and remunerative use of the railways could justify the great expense of this. Subsequent doubling of lines is always more expensive than laying the original line, because the doubling is only necessary or sound when traffic has become heavy; and then the country has become settled, population denser and land dearer, and it may be necessary to buy and demolish costly buildings on valuable sites for the purpose.

It often happens in continental railways that wide barren or desert strips have to be "bridged" by the railway to connect settled districts. On such stretches there is no local trade, and in themselves they are unremunerative. They may also be very costly to build and maintain: desert sands may block the line; water may be absent and must be supplied by railway carriage, or by the provision of long pipe-lines, and possibly expensive pumping plants. Such a line is the new Australian railway from Perth, Western Australia, to Adelaide; and that particular line has to struggle against the cheaper and very

efficient, if slower, sea transport across the Australian Bight. Examples of the same thing are found in the more southerly of the United States trunk railways.

Freights.—The income of the railway must first of all bear the interest on the heavy first cost. Then it must provide for maintenance, and a sinking fund for the liquidation of debt, and for extension and development. Next there are the costs of working to be met, charges for handling the goods, insurance to meet the liability of the railway company for damage to goods while in their hands; and after that there must be a profit for the shareholders. Each freight charge must contribute its share under each of these heads, and the charges are based on these costs. The due share of different types of goods under the various heads differs according to the nature of the goods. Fragile material requires more careful and therefore more costly handling than material less easily broken, or less damaged by breakage. It is usually more bulky for its weight than other articles, and requires more room in trucks. It requires shelter in transit and at stations, and makes greater demands on the company's insurance scheme. The rates for fragile goods, such as furniture, are therefore higher than those for coal or pig-iron. Rates must also be fixed with a view to the effects of competition. Such a commodity as coal will, as a rule, go by the cheapest means of transport. It is not perishable, and it does not demand rapid transport. Where there is coal to be carried it forms an overwhelmingly large proportion of canal traffic, though that carried by canal is much less, as a rule, than that carried by competing railways. The coal traffic is a large one, and it pays the railway to carry it cheaply, preferring a smaller rate of profit in view of the larger

total net income to be drawn from a large trade. The British railroads were built to be used, like the canals, by the vehicles of anyone who cared to pay for the privilege. Their profits were to be made from *tolls* levied for the use of the lines. Hence British charges are made as "tolls, rates, and charges", suggesting the different heads under which freights must be assessed. Goods are classified for charges, and the present classification is based on a rough one used earlier by the canals. This classification was drawn up by the Railway Clearing House, an institution established by the companies for the adjusting of claims arising between them in respect of the services rendered to each other. (These services arise in connection with through traffic, in which goods and passengers, booked on one company's system for the complete journey, pass over those of other companies with the same ticket.) This classification has been made the legal basis of the rates chargeable by railways. There are now eight classes, A, B, C, 1, 2, 3, 4, 5. In class A are such things as coal, undressed stone, ores, manure; in B, brewers' grain, copper-ore, metals, timber, vegetables; in C, steel, heavy machinery, earthenware, cured fish, raw cotton, tin-plate; in 1, lighter metal and metal goods, implements, gas-engines, grain for food, preserved meat; in 2, brass goods and light metal implements, machines; in 3, aluminium, leather goods, calico and heavy drapery, eggs, fruit, spirits, hardware, and small engines; in 4, live animals in packages, carriage bodies, furniture in vans, fresh meat, and fish; in 5, bicycles, musical instruments, flowers, and carved woodwork. The railway rates were fixed by law as they stood in 1894, but since 1913 they have been raised by Government permission to meet in-

creased cost of working, chiefly due to wages increase.

We shall now glance rapidly at certain features of the railway systems of certain lands, and the student must follow carefully, atlas in hand.

North American Railways.—The railways of North America are very interesting. The country consists of an eastern coastal plain backed for the most part by the Alleghanies and mountains in the same general line. West of these is the great central plain rising very gently from the Gulf of Mexico to the Canadian border, and falling thence, also gently, to the Arctic Seas. West again is the gigantic barrier of the Rockies, broadest and highest in the United States. From Denver to the Sacramento the mountain belt is about 16 degrees of longitude wide, or 850 miles; while from Calgary to the sea is only 10 degrees, and the mountain belt (above the height of 6000 ft. in both cases) is less, say some 400 miles wide. The railways ramify over the coastal plain of the east and south, and the great plains. Through the mountains they rather stretch long arms, feeling for the lower passes. Note the importance of the Hudson-Mohawk and the Hudson-Lake Champlain valleys in the north-eastern States and the valley of the Thompson River in British Columbia. On the west the transcontinental trunks throw off branches along longitudinal valleys (e.g. Sacramento-Joaquin Valley) or along the coast. Very close networks surround the great lakes: on the Canadian side only in the east, and this is obviously due to the fact that lake navigation and the railways have developed in concert. The industrial regions are mainly situated in a belt between the parallels of 40° and 50° N., extending west not farther than the meridian of 100°, and the railways within this belt show by far the closest network.

Railways of Europe.—Whereas North America is a large compact land mass, Europe, merely the western peninsula of Eurasia, is much cut up by the sea, which provides avenues leading into its heart. The great Asiatic Plain extends across Russia to the Black Sea, and across northern Europe to the Atlantic. To east and west communication there is little in the way of barrier in the north, but the sea provides the cheaper alternative both here and in the Mediterranean. Excepting in the east, therefore, the most important lines run from north to south. Across this direction lie the main mountain barriers, but, compared with the Rockies, the Alps, some two degrees in width, are a trifle. The Rhone and the Danube provide passages at either end, and there are numerous passes in the mountains which are, without remarkable difficulty, made to accommodate the railway. The chief are Mt. Cenis, leading from the Rhone Valley to Turin, the Simplon, carrying the line from Paris to Milan, where the St. Gothard route joins up to proceed to the Italian ports. The Brenner Pass leads to Verona; the Semmering carries the (late) Austrian route to Trieste and the Adriatic. / A more serious barrier is the high, narrow, but even ridge of the Pyrenees, which the railway does not cross, but skirts at each end on the narrow coastal strips by Bayonne and San Sebastian for Madrid and Lisbon, and by Narbonne, the Col de Pertus, and Barcelona for the east coast of Spain. The chief east and west lines cross from Paris by easy country through Belgium, Cologne, Berlin, Petrograd, and Moscow, skirting the Urals on the south to join the trans-Siberian line; and from Paris between the Vosges and the Jura by the Belfort Gate, and thence by the upper Rhine

and the Danube valleys to Munich, Vienna, and Constantinople. The western part of the plain, in northern Germany and France, and the English Plain are the busiest parts, and there the railways are closest. The great plains of the east are generally undeveloped, but they are easy railway country, are rich in parts, and will no doubt carry a close network of lines in the future. One misses the great "development" lines, which in North America, pushing out into the west, are such a conspicuous feature.

Railways of Great Britain.—In our own country the railways centre on London. Over the Midland Plain, with its great industries and close population, there is the main network, which penetrates South Lancashire by the Midland Gate, and extends into Yorkshire. The Pennines divide the northward lines, which cross the Scottish border by the coastal strips on either side of the Cheviots, and give importance to Berwick, and add to that of Carlisle. The southward lines are largely connected with continental traffic to the "ferry" ports, Dover, Folkestone, and Southampton, mail traffic to ocean liners (Plymouth), and defence (Portsmouth) (fig. 115). The Grampians are skirted on either side, and crossed by Drumochter Pass; but only the low east coast of the north of Scotland has been able to attract railway communication. In Wales railways thin out among the mountains. The arrangement of the South Wales lines is interesting. They depend for through communication on the coastal flat which skirts the high land, and reach the mining and industrial districts by radiating valleys. In Ireland an open net spreads over the Central Plain, and tongues penetrate through the mountains to the coast. In the south-west the lines

Fig. 115

make a regular rectangular pattern which a colour-layer map explains at a glance.

Railways in other Countries.—In new countries the railways tend to be coastal lines, pushing branches into the interior where it is becoming known and is fit for settlement. The east of Australia provides a good example. Africa has a special interest, on account of the form of the continent. It is mainly a vast plateau rising from two to three thousand feet above the sea (except the Sahara) (cp. fig. 84). There is a narrow, low coastal border, above which towers the plateau scarp, a formidable barrier to the railway. The rims of this scarp are somewhat raised, and the rivers tend to run across the continent, reaching the coastal plain by a steep descent which produces falls and rapids, and blocks navigation. On the plateau and on the plain such great rivers as the Congo are ideal for trade by water, and short lengths of railway have been built to carry this trade past the cataracts. The early stage of railway construction was, in the case of the Congo and the Nile, confined to this; but there are now several lines leading from the coast well into the interior in various parts of Africa, while in the Union of South Africa the steep ascent to the plateau has been made successfully at more than one point, and a railway network is well on in the making.

In Japan we find a long, narrow mountainous region rising steeply from the sea, the only low-lying part of any extent centring on Tokio. For long Japan was exclusive and conservative, and this, together with the nature of the country, and the convenience of sea communication, prevented the development of a system of good roads. Here we have a railway system preceding the road system. The railways are mainly coastal, with a few lines penetrating some way into, or even crossing, the mountains, by the scanty through-valleys.

CHAPTER IX

OCEAN TRANSPORT—I

In this chapter we have to consider the conditions imposed directly by nature on communication by sea, and the devices employed by man in response to them. Sea communication involves the provision of routes and ports; and though the great sea-ways cannot be marked, they must be known sufficiently to enable them to be followed with certainty and expedition.

Ports.—Harbours must provide safe berths for ships, whether at anchor or moored to quays, deep water, and freedom from obstacles to navigation. For so much they depend directly on nature. If they are used merely as temporary refuges, no more is needed; but if they are commercial ports, they must be situated conveniently for the internal commerce and industry of the country, must be provided with proper wharf accommodation and equipment, and with railway facilities for inland communication; with victualling and coaling arrangements; and with slips, docks, and workshops for the repair of ships. For these man is responsible. Safety is provided by natural obstructions to the winds and seas. Land-locked inlets, even if they do not extend far into the land, deep and winding gulfs, and long estuaries make good harbours; for example, Cork Harbour and Port Philip; Milford Haven, the Norwegian Fiords, and Port Jackson; the Thames and the Forth. Often a harbour is exposed in some direction, and when a high wind blows from that direction the harbour becomes unuseable, like that

at Folkestone. It is most important that there should be shelter from prevailing winds, and from directions the winds from which are frequently stormy; but the provision made by nature may be increased to some extent by the erection of breakwaters, as at Plymouth and Leith.

Many harbours are tidal; that is, they depend for depth of water on the rise of the tide, and are only able to be entered or left near high water. In order to keep ships afloat continually, docks with gates or locks must be provided; such are only open for a comparatively short period when the tide is high. Many ports on estuaries, particularly old ports which for security from attack were originally placed as far up the estuaries as possible, have these tidal locks to deal with the great draught of modern shipping never contemplated by the founders of the ports. In some cases, as on the Clyde, the existence of great ports on rivers naturally shallow depends entirely on artificial deepening of the channels by excavation and continual dredging, as well as on the extra water provided by tides with a great rise and fall.

Silting up of Harbours.—Rivers bring down a certain amount of sediment from the land, and the faster they flow and the larger they are the more sediment they bring. This sediment is dropped in their estuaries, because whenever their speed of flow is slackened by the sea they lose their carrying power; so that estuarine ports continually tend to be silted up, and their existence depends on dredging out the silt as quickly as it is deposited. Not only so, but this silt, with the sand and mud which abound on the shore, is caught up and carried by currents sweeping along the coast, and is liable to be deposited in

banks and bars across the mouths of bays and inlets. Thus are formed the shingle bars that often cut off partly or completely land-locked shallow lagoons on our coasts (cp. the *Haffs* on the southern shores of the Baltic). Many otherwise serviceable harbours are hampered or spoiled by longshore currents, often tidal currents, building bars across their entrance at a rate which cannot be met by such dredging as the port can afford; and as these tidal currents are strong on coasts where the rise and fall of the tide is high, tidal ports are very liable to this disadvantage. On the other hand, tidal currents may tend to sweep away the silt brought down by rivers, and keep the estuaries clear. The mouths of the Po and the Danube in the practically tideless Mediterranean and Black Seas are heavily encumbered by banks and shallows on account of the absence of tidal scour.

As to the ocean highways, knowing the positions of the terminal ports and of dangers and difficulties to be encountered and avoided, it is easy to determine the best and shortest course for the ship to steer. To enable the course to be kept the mariner requires instruments for his guidance, the compass and the log. His ship is liable to be driven out of her way by winds and tides, and so he must be able to determine his position from time to time in order to see whether he is keeping the right road. This he does astronomically by means of the sextant on the methods discussed in Chapter II; and the chart is his map, on which he follows out his progress. Winds have been discussed as far as practicable in this book in Chapter VII, and charts in Chapter VI. It remains to study here tides and ocean currents, the compass and the log, and the methods used by the navigator in setting his course and following it out.

Tides.—The tides depend on gravitational attraction between the earth and celestial bodies. To gravitational attraction is due the tendency to approach each other that exists between any two bodies in nature. It is such that the greater the mass of the bodies the greater is the attraction in direct proportion, and the more distant the bodies the less the attraction in the proportion of the inverse square of the distance: that is, if the distance between any two bodies is doubled, the attraction between them is reduced to a quarter; if the distance is trebled, the gravitational attraction is reduced to a ninth, and so on. The moon is large enough and near enough to the earth to produce a tide. Think of the earth as a solid core surrounded by water which, but for the attraction of outside bodies, would cover it evenly all over. The attraction due to the moon on the water on that side of the earth next to it is greater than the attraction due to the moon on the solid earth under the water; which attraction in its turn is greater than that on the water on the opposite side of the earth. This is because these are at greater and greater distances from the moon. Now the earth as a whole is maintained in its place in space by the balance of the attractions upon it of all the heavenly bodies; but the water on the side of the earth next the moon being attracted more powerfully by the moon than the solid earth beneath, bulges up under the moon, while the solid earth in its turn is, as it were, pulled away from the water on the other side of it. But the earth, being solid and rigid, must accommodate itself as a whole to the pull of the moon's attraction. The water, on the other hand, can flow. This water is held on the surface of the earth by the earth's gravitational

attraction. Hence, it is under two forces, the gravitational attraction of the earth, which acts along the radius of the earth, and the difference between the attraction of the moon on the water and on the solid part of the earth. On the one side this last force pulls the water away from the earth, on the other it pulls the earth away from the water, which amounts in the result to the same thing. Hence, the resultant of these forces tends to pull the water on either side of the earth towards the line joining the earth and

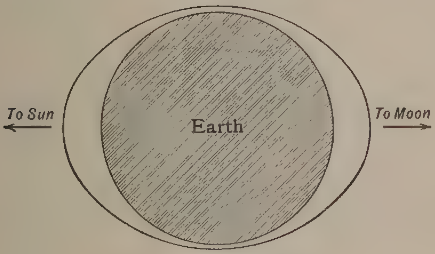

Fig. 116*a*.—Spring Tides

the moon, as is shown in fig. 116*a*. The fluid water, accommodating itself to these forces, bulges out on either side of the earth "under the moon". The sun is the only other celestial body which produces appreciable tides on the earth, and though it is much more massive than the moon, it is also so far distant that it produces smaller tides, but in the same way. The bulges of the lunar and solar tides do not occur in the same places unless the sun and moon are in the same straight line with the earth, either on the same side of the earth, or on opposite sides of it. On these occasions the two tides reinforce each other, and hence at full and new moon, or "full and change of the moon", there are large tides

or **spring tides.** At other times the two tides interfere with each other, and they do so most when the sun and moon are in quadrature, that is, when the lines from the earth to sun and moon are at right angles. These are the times of first and last quarter of the moon, and at these times occur **neap tides**, which are roughly half as high as springs (fig. 116*b*). Since the moon is full once a lunar month, and new once

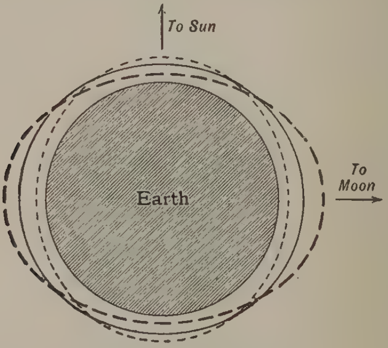

Fig. 116*b*.—Neap Tides

in the same period, spring tides occur once a fortnight, and neaps once a fortnight.

The rotation of the earth carries the waters upon it round, so that the bulge, remaining under the moon, *appears* to travel round the earth in the direction opposite to its rotation. The bulge behaves like a wave, in that, though the water as a whole is not transported, the alteration of its level is. Each particle of water moves mainly up and down, but also very slightly forward on the up-movement, and backward on the down-movement; "forward" meaning in the direction in which the wave travels

or appears to travel. This tidal wave in the open ocean rises about two feet, so that the tide on ocean shores with deep water fairly close in-shore is quite small. As the water shallows the deeper movements of the water-particles are interfered with by friction against the bottom and resulting confinement of movement in the deeper layers (fig. 117); that is, the downward and backward movements of the particles are suppressed, and the water moves bodily forward as a *tidal current*, and piles up into a higher wave. Hence the tidal currents and high tides in the shallow seas of Great Britain. In funnel-shaped estuaries the continual narrowing of the channel increases the piling-up process, and *bores* occur, as in the Bristol Channel and other places.

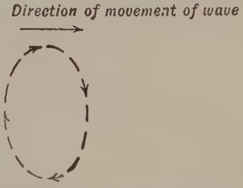

Fig. 117.—Movement of each Particle of Water in a Wave

Of course the earth is not as we have pictured it, but the picture serves to show from the simplest case the mechanism of the tides. If we think of the earth as it actually is, we observe the continents stretching out as dams across the course of the tidal wave and forcing it to follow indirect paths from ocean to ocean. Take the wave as beginning its course in the Pacific; America forces it to move southward and enter the Atlantic round the Horn, where there it finds the widest channel open to it. Thence it must sweep north into the Atlantic, and so it approaches our shores obliquely from the south-west. The flood tide runs as a current north along our coasts, and reaches the North Sea by the north of Scotland, but partly also by the English Channel. The two tidal currents meet just beyond the Straits of

Dover laden with silt swept up from the shores, interfere, and bring each other to a stop, with the result that the load of sand and mud is dropped and contributes to the great shallow banks which form the famous North Sea fishing-grounds. Tidal charts show the progress of the tidal wave; the hour at which the crest of the wave reaches each position, or the time of high water in those positions, being indicated by lines of the contour type drawn through all places having high tide at the same time. These are *cotidal* lines.

Currents.—In shallow waters currents are largely tidal currents. Surface currents in the free oceans are often "drifts"; the wind sweeps the surface waters along before it just as a fresh breeze ruffles the surface of the water and sweeps off the crests of the waves. The currents of the deeper layers of the ocean differ from those at the surface, but it is only with the latter we can concern ourselves at present.

A simple way of determining surface currents is to drop a bottle or a piece of wood into the sea, and to watch and note on a map the direction which it follows. It is better if the float be weighted so as to swim just under the surface, because then it will not be drifted directly by the wind which happens to be blowing. Much of the study of the ocean currents of the world has been carried out by launching from many places at sea fleets of weighted bottles, each containing a record of the point at which it was set free. Information about the fate of as many as possible is collected from ships which have picked them up at sea, examined them and noted on the paper inside the place where they were observed, and from those who have found them when at last they were driven ashore. Much of the information regard-

ing currents comes also from the courses of ships at sea. Suppose a ship sets a course at A which ought to bring her to B (fig. 118). She finds that at the time she expected to make B on this course she has arrived at C. She has been driven out of her way by the amount BC. From our lessons at school in the composition of velocities, we see at once that the ship's steaming has given her a speed which would carry her to B; but that she has had an independent movement, of velocity sufficient to carry her in the same time from B to C. She owes this other movement to drift by the winds, which is called *leeway* at sea, and to drift by currents. The ship steams at 10 knots say, and the distance AB is 40 (sea) miles, the direction being north-east. She has been steaming four hours. The distance BC is 8 miles, the direction south-east. The total drift is therefore south-easterly, 2 knots. If the amount (and direction) of leeway can be taken off, the balance is the speed and direction of the current.

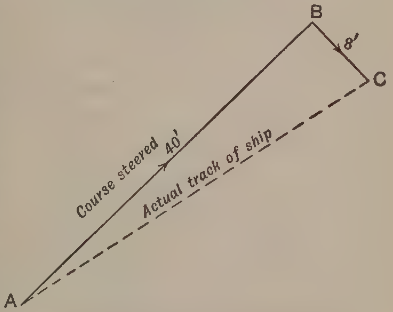

Fig. 118.—Effects of Currents on Ship's Course

General Ocean Currents.—Apart from the tidal currents, each ocean has its own general scheme of currents, and these take the form of great eddies which sweep round the oceans in the same direction as anticyclones in the air above them; thus, the North Atlantic has a clockwise eddy, the water north of the equator moving westward in the north equatorial

current, turning northwards along the east coast of America, and bending eastwards towards Europe. There the eddy passes southward as the Canaries Current, which, joining up with the north equatorial current, completes the eddy. The South Atlantic has an eddy turning in the opposite, or counter-clockwise direction. Similar eddies, but more simply developed, are seen in the Pacific. In the North Atlantic, the waters of which are naturally best known, there are complexities. These are due to the arrangement of the land about the ocean. A rather false impression of the shape of the North Atlantic is given by the Mercator map, from which most people derive their ideas of it, because the distances between the tips of South Africa and South America, and between the north of America and Europe are so much exaggerated by the projection (cp. fig. 121). The westward bulge of Africa, running out just north of the equator, overlaps the eastward bulge of South America, running just south of the equator, and forms a channel for the waters such that the south equatorial current, forced against the eastern angle of South America, splits upon it, and in part flows along the north coast of South America to reinforce the North Atlantic eddy. An arm of this eddy enters the Caribbean Sea by the many passages among the Lesser Antilles, but it has only a narrow passage north of the Greater Antilles for escape from the Gulf of Mexico. There is therefore a brisk current passing outward through the Florida Strait, which has been called the Gulf Stream. The strengthened eddy as it flows along the east coast of the United States is still a definite current, and the term Gulf Stream is extended to cover it also. Across to Europe there moves a north-eastward drift of the

surface waters, which in earlier days was taken too seriously, and it also was referred to as the Gulf Stream; but its character is very different from that of the stream flowing along the American coasts, which moves at the rate of a knot or two, whereas the North Atlantic drift, as it is now called, only has a speed of some four sea miles per day. The Gulf Stream, properly so called, leaves the immediate vicinity of the coast, and gradually falls off and disappears after it reaches Cape Hatteras.

Before so much was known about these currents as nowadays, it was believed that they flowed regularly in determined courses like great ocean rivers. Now we know that they are much less constant and regular. It was believed that they were due entirely to differences in the sea-water: differences of temperature setting up differences of pressure like those we find causing winds in the air; and differences of salinity, or the amount of salt in the water. But there is reason to believe that surface currents are largely controlled by winds, and vary with the direction and strength of the winds. In the Indian waters we find a reversal of the surface currents follow the monsoon reversal of the winds. One would expect to find constant currents follow constant winds, for example, in the Trade Wind belts; and the Canaries Current appears to support this. But on the other side of the Atlantic we find the strong Gulf Stream opposing the Trades. There can be no doubt, however, that although there is still much for us to learn on the subject, we are justified in believing that winds have a profound influence on ocean currents, and that the North Atlantic drift, with its long north-eastward extension into Arctic waters, is due to the prevailing westerly winds above

it. Differences of salinity and temperature have their effects. Cold water is heavier than warm, salt water than fresh. Therefore warm water and fresh water both tend to float on the surface. But cold fresh water may be heavier than warm salt water, or it may be lighter. The surface water of the North Atlantic drift, flowing from lower to higher latitudes, is warm. Off Newfoundland the drift meets a surface current of cold fresh water, the Labrador current, coming down from the melting ice of the Baffin Sea. This cold current overrides the warm but salt drift at first, but as it proceeds south into warmer waters, its water at length encounters northward moving salt water warm enough to be lighter than it, and in its turn it is overridden, and disappears as a surface current near Cape Hatteras.

Water moving from low to high latitudes is naturally warmer than the water, and even than the air, which it encounters. Hence currents moving from low latitudes are warm currents, those moving from high, cold. Such currents have a profound effect on climate, in respect to temperature and rainfall. Being warm, they warm the air above them and increase its power of carrying water vapour. But it must not be thought that these currents act like the hot-water pipes in a hall. They would be ineffective but for the winds. The east coast of the United States and the west coast of northern Europe are bathed by warm currents; in the latter case climate is profoundly affected, in the former not at all. The reason is that in the latter case the prevailing winds blow on-shore across the warm surface water to the land, while in the former case they blow off-shore from the land across the drift. The temperature of these currents is not so remarkably high

in itself; it may be a couple of degrees or so above the natural temperature for the latitude. But the high specific heat of water makes it a great storehouse of heat, and enables it to warm a great deal of air, because for the purpose it need part only very slowly with its warmth. The effect of the warm currents on rainfall is suggested by the foggy conditions off Newfoundland. The warm, moist air blows across the drift on to the chill waters of the Labrador current, which speedily cool it and reduce its power of retaining moisture, so that its excess of water condenses and produces the fogs.

Sea Routes.—Since the great circle is the shortest path between two points, it is the one the mariner would naturally choose, provided it were practicable. Sunderland and Suva (Fiji Islands) are on the same meridian (regarded as a complete circle, i.e. their longitude differs by about 180°), so the great circle course would be the meridian, which would lead through the pole. Such a route is not practicable. Often land comes in the way and breaks the great circle course, and in such cases it is necessary to follow two great circles which intersect off the farthest point of land in the way (e.g. Great Britain to Australia, one great circle to the Cape, another to Australia: or one great circle to Panama, for the canal, the other from Colón). It may be necessary to deviate from the part of the great circle course otherwise practicable, as in the case of sailings to New York from this country, where the great circle leads into the ice- and fog-infested waters off Newfoundland. The old sailing ships, for which time was not usually so important as it is for the modern steamer, with its valuable or perishable cargo, and impatient passengers, used the rhumb-line, or Mercator's sailing.

Parallel sailing consists in following the parallel, and **plane sailing** in regarding a part of the earth as a plane, which suffices for short passages, but is useless for long. Since the sailor uses Mercator's chart, for the reasons given in Chapter III, he always uses the rhumb or Mercator's sailing really; but instead of sailing the whole way on the long direct rhumb-line from port to port, he divides up his voyage, determines the latitude and longitude of places on the course he means to use, great circle if possible, and sails on short rhumbs between them. Thus he can plot his route on the chart as a chain of straight lines, and does not need to be continually altering course. The shorter the rhumbs the more often he has to change his course, but the closer he keeps to the great circle.

In order to simplify the calculations, the points thus selected are never so far apart that there will be a great error in neglecting the curvature of the earth. The passage from point to point is plane sailing. Let it be from A to B, the latitudes being ϕ_1, ϕ_2, the longitudes l_1, l_2, and let fig. 119 show these plotted on the chart. Draw AM and BP, the meridian through A and the parallel through B, and let these meet in C. On Mercator's projection meridians and parallels appear as straight lines, and these, as on the earth, cross at right angles, so that the triangle ABC is right-angled at C. Now a minute of latitude is equivalent on the surface of the earth to one sea mile. Hence, if we set off the distance AB by means of a pair of dividers along the latitude scale, we can read off the distance in miles. Clearly, the longitude scale on the map is of no use for this purpose. To find the bearing of the course from A to B we have only to measure

the angle CAB. The distance and bearing can also be calculated with ease. The difference of latitude between A and B is represented by AC. It is found from the co-ordinates by subtracting the lesser latitude from the greater, if both are north or both are south; but, if the one is north and the other south, it is found by adding the two latitudes. Reduced to minutes, it gives the distance in sea miles between the parallels of A and B, and this is what the sailor

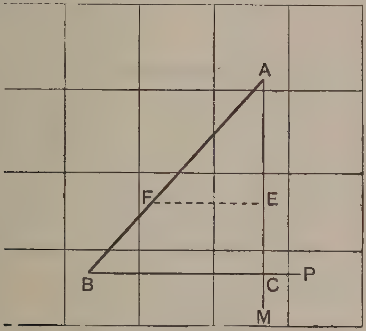

Fig. 119.—Plane Sailing

usually means when he talks of the difference of latitude, or, in short, D. Lat. of two points. The difference of longitude is the angle between the planes of the meridians of the two places. It corresponds to different lengths according as it is measured along the parallel of A or of B, if these are not in the same latitude; but in plane sailing D. Lat. is small, and we need take no account of the difference. Reduced to minutes it does not give the distance along the parallel between the two meridians, but the distance between them on the equator. To find the distance along the parallel it is necessary to multiply by the cosine of the latitude (refer back to Chapter I, p. 14).

This distance in sea miles is called the *departure*. Referring again to fig. 119, we see that AC represents the D. Lat., BC the departure, AB the distance between the points, the angle CAB the course. Then:

to find course, tan course = departure/D. Lat.;
to find distance, distance = D. Lat. × sec. course.

In ocean voyages one cannot assume the sailing is plane; the distance between points is too great. But let the same figure represent this case. The chart is orthomorphic, and therefore we can still measure the angle CAB to find the course. But the distance BC on the chart is the same as it would be at the equator; it is therefore the difference of longitude (D. Long.), and the distance AC is the difference (algebraic) of the meridional parts corresponding to the latitudes, what is called the meridional difference of latitude (see Chapter III, p. 75). Hence to find the course, we have:

tan course = D. Long./Mer. D. Lat.,

the D. Long. being expressed in minutes of angle.

To find the distance we must lay off AE proportional to the actual D. Lat. in miles. This is smaller than the Mer. D. Lat., for the scales are exaggerated in the chart. Draw EF parallel to BC. EF represents the departure, and AF the true distance; then, from triangle AEF.,

Distance = D. Lat. × sec. course.

If we wish to measure the distance directly, we can apply the length AB to the scale of latitude as before. But to what part of the scale? Find first of all the mean latitude of the points; that is, take half the

sum of ϕ_1 and ϕ_2. This will be the latitude of the middle point of AB (on the earth, *not* on the chart). We must place the dividers on the scale of latitude so that the middle of them is over the mean latitude on the scale.

EXAMPLE: A is in Lat. 51° 42′ N., Long. 7° 21′ W.
B ,, 43° 19′ N., ,, 16° 54′ W.

Lat.	51° 42′	Mer. Pts.	3 636·1	Long.	7° 21′
	43° 19′		2 889·2		16° 54′
Diff.	8° 23′	Mer. D. Lat.	746·9		9° 33′
	60				60
D. Lat.	503′			D. Long.	573′

(1) Course, log D. Long. (log 573)	2·758 15
log Mer. D. Lat. (log 746·9)	2·873 26
log tan course	9·884 89
Course	37° 30′
(2) Distance, log. sec. course	10·100 53
log D. Lat. (log 503)	2·701 57
log distance	2·802 80
Distance	635·0.

Therefore the course is 37° 30′ west of south (refer to fig. 119) or 217° 30′ (bearing from true north), distance 635·0 sea miles.

Mariner's Compass.—Having found the course to be followed, one depends on the mariner's compass for keeping it. On board ship this consists of a hemispherical brass bowl weighted at the bottom, and swung on gimbals, which allow the compass to remain comparatively steady when the ship rolls or pitches in a sea-way. Rising from the bottom of the bowl is a steel pillar, finely pointed and tipped with iridium, which is hard enough to resist wear and does not rust. On this pivot sits an inverted brass cup, the bearing part being an agate or ruby

centre. To this the card (fig. 120) is fixed by means of fine silk threads. The card is a circle of thin paper with an aluminium ring round its circumference for rigidity. The centre of the paper circle is cut out, and under it are suspended a set of fine magnetized needles, parallel to one another, half being arranged symmetrically on either side of the centre. This arrangement is very light, and so bears gently on

Fig. 120.—Compass Card

the pivot, wearing it very little, and comes to rest much more quickly than the heavy old-fashioned compass card. It sags a little, carrying the centre of gravity below the pivot, and this gives stability. The upper side of the card is divided into "points" in the familiar way, and also into degrees. Inside the bowl is drawn a black line passing from one side to the other through the base of the pivot. This is the "lubber line", and the compass is mounted so that it is in the fore-and-aft line of the ship, and indicates the course on the card. The gimbals are fixed on springs in the binnacle, which

is a waist-high pillar standing just for'ard of the wheel. The binnacle also carries devices for correcting the indication of the compass, and on its after side a plummet or clinometer to indicate the angle of heeling or rolling of the ship.

In the old days of wooden ships the compass was a much less refined instrument than now. Steering by "points" was all that was attempted. These were:[1]

4 Cardinal points, N., E., S., W.
4 Quadrantal points, N.E., S.E., S.W., N.W.
8 Intermediate points, N.N.E., E.N.E., E.S.E., ...
16 By-points, N. by E., N.E. by N., N.E. by E., E. by N., ...

To be familiar with these is to be able to "box the compass". The introduction of steam and steel ships, and the modern money value of time, has made more accurate work necessary. Steering by degrees is therefore usually practised, though sometimes quarter points are used, as S.E. by E., ¼ E. (¼ point E. of S.E. by E.), in spite of clumsiness.

Errors of Compass.—The compass points to what is called magnetic north, not true north. The difference between magnetic and true north is called "declination" ashore, "variation" afloat. In this country the magnetic needle points between 15° and 22° west of true north. The variation is therefore from 15° to 22° W., being least in the south-east, greatest in the north-west. It changes at any place from year to year: at present in this country it is decreasing 6′ to 9′ annually. It was zero in 1657 having been east before. It began then to be west and reached its maxi-

[1] There are thirty-two points to the 360° of the circle: each point is therefore equal to 11¼°.

mum in 1816, and will continue decreasing till 1977, when it will swing east again, increasing till 2290. This is due to the fact that the magnetic pole swings in a circle about the geographical pole, taking some 640 years to complete the circuit. The variation at any time is shown on special charts by *isogonal lines*, which pass through all points on the earth having the same variation. If we know the variation and its rate of change for a given year it is easy to find the variation for a subsequent year, provided the interval of time is not too long; if the interval is more than ten or a dozen years, changes and irregularities of the rate are apt to produce significant errors. Having given the variation, it is easy to convert true into magnetic bearings or *vice versa*. This has to be done when a course which has been calculated is to be set, for one works with the true bearing in the calculations, but follows the course by compass, using magnetic bearings. The student must think out the simple rule:

> Variation west, add to true, subtract from magnetic bearings;
> Variation east, subtract from true, add to magnetic bearings

to convert true to magnetic or magnetic bearings to true, respectively.

Variation is not the only error from true directions with which the sailor has to reckon. Everyone who has used a compass much knows that each compass has its own additional error; but the ship also introduces an error, particularly if she is of steel or if she has an engine. If a piece of soft iron be held in the magnetic meridian and hammered it will become a magnet. In the process of building, the ship lies still in one direction and is subjected to continual hammering, which causes her to become

magnetized, the position of her poles depending on the position in which she lies. Launched and in commission she turns here and there, is subjected to the buffeting of the waves and other shocks, and so she remains a magnet with ever changing poles, and with effects on her compasses which are therefore always changing. Part of this effect is neutralized by appliances placed in and about the binnacle and adjusted periodically to changes in the ship's magnetism. First, there is a series of small magnets within the binnacle, lying in various directions, whose aim is to balance the permanent magnetism of the ship. Second, on either side of the binnacle on a level with the compass, there is a ball of soft iron which can be moved when necessary closer to or farther from the needle. Whereas steel tends to retain its magnetism, soft iron tends to change it in accordance with the magnetic influences acting on it. As the magnetism of the ship alters, so does that of the balls. Lastly, within the pedestal of the binnacle, or in a brass tube on the fore side of it, is a bar of soft iron, placed vertically. This is the *Flinders Bar*, and its purpose, like that of the balls, is to neutralize changes in the magnetism of the ship. These devices only lessen, they do not eliminate the errors of the compass, and there is always a difference between north by the compass and true north after the variation has been applied. This is called *deviation*. It varies from time to time, and it varies with heeling of the ship and the direction of her head; and the only way to avoid the trouble it causes is to have it determined and noted regularly. This is done in the process of "swinging ship". At sea one takes astronomical observations for azimuth or true bearing of the ship's head, the reading of the compass being

noted at the same time. Having converted the true bearing into magnetic by applying the variation, the difference between the true magnetic bearing and that read on the compass is the deviation. This is repeated with the ship's head in several directions, it may be every point of the compass; and the term "swinging ship" refers to this changing of her head. The values of the deviation are tabulated against the direction by compass. It may well be that this is done in places for which the mariner has no knowledge of the variation; he must then be content to slump the difference between true directions and the corresponding directions of the compass as *compass error*. If ship be swung off a charted shore observations for azimuth need not be made. The position of the ship may be resected and plotted on the chart, and true bearings obtained by observations to prominent points ashore which appear on the chart.

Example:	True course by observation, S. 46° 17′ W., or, adding 180° to get ordinary bearing	226° 17′	
	Variation (from chart)	19° 45′	W.
	Magnetic bearing (sum)	246° 02′	
	Course by compass, S. 59° W., i.e.	239°	
	Deviation of compass	7°	E.

The deviation is called east because the course by compass *appears* to be to the left of the actual magnetic course, and north by compass is to the right or east of true magnetic north. The difference between the course by ship's compass and the course true is called the error of the compass and is called east or west in the same way.

Example:	True course by observation	N. 16° 43′ E.
	Course by compass ...	N. 41° 30′ E.
	Compass error	24° 47′ W.

This error is west because the compass course reads to the right of the true course, or, the true course reads to the left of that by the compass. If the variation were known to be 7° 15′ W., the deviation would be 17° 32′ W.

Example: Set a compass course on the true bearing E. 41° 30′ S., the variation and deviation being 17° E. and 29° W. respectively. (It is an excellent plan to draw a little diagram in working examples.)

Course true	E. 41° 30′ S.
Variation (subtract)	17° E.
Course magnetic	E. 24° 30′ S.
Deviation (add since it is west)...	29° W.
Course by ship's compass	E. 53° 30′ S.

There is not much point in working out deviation to less than $\frac{1}{2}°$, because a course cannot be steered closer, nor can the compass be depended upon to so little. It is usually clearer to work all examples like the first with directions reckoned "right round the clock" from north than as in the next two; but the latter method is commoner with sailors.

The distance run by the ship is measured by means of the log. In more primitive form, still used occasionally, this consists of the log-ship, log-line (hand-line), and sand-glass. The last is like the sand-glass used still to time the boiling of eggs, and usually depicted in the hands of Father Time. For sea use it was made so that the sand took twenty-eight seconds to run out; but it is seldom used now, a watch being preferred. The line is wound on

a reel, which nowadays is fitted with a brake. On this line a knot is tied every 47¼ ft., which is the distance a ship doing one knot covers in twenty-eight seconds; but why twenty-eight seconds should have been selected is not known. These knots can be felt even in the dark, and so the number passed out while the glass runs is always easy to ascertain, and gives directly the ship's speed in knots. Hence the term. The end of the line is made fast to the log-ship, which consists of a sector of a wooden disc, weighted along the curved side so that it floats upright. There are two holes in the log-ship at the lower corners. The line is made fast permanently to one, while a peg fitting the other is tied to a short piece of line attached to the log-line, so that the log-ship lies at right angles to the line on which the ship is sailing, and so by the resistance of the water tends to remain still while the ship moves away from it. One man holds the reel at arm's length above his head, the other drops the log-ship over the stern of the ship, and allows the line to run through his hand so that he may be able to count the knots. The first knot occurs some way, usually 100 ft. or more, from the log-ship, so as to let it get out of the disturbed water in the immediate wake of the ship before the glass is turned and counting begins. When the sand has run out a jerk on the line pulls out the peg, and allows the log-ship to fall off parallel to the course, and to be hauled aboard more easily. Nowadays the patent log has ousted the old-fashioned log. It consists of a brass cylinder with slanted fins, fixed propeller-wise along its sides. This is towed astern on a plaited log-line which will not untwist or "kink". The fins make the cylinder rotate at a rate depending on the speed of

the ship, and this rotation is communicated to the log-line, which carries a fly-wheel to steady the turning. On the counter of the ship is fixed an indicator to which the twisting log-line is attached, and in which it turns a series of toothed wheels registering on a dial every sea mile run by the ship. This is read at definite intervals, and so the mean speed can be deduced. In modern times the indicator is connected electrically to the bridge, to which its indications are transmitted. On large ships the electrical arrangements enable the speed of the ship, and not merely the distance run, to be read directly.

Having given the course and the distance run on it, the sailor can find right away the change in his latitude and longitude from Traverse Tables, also called Tables of Differences of Latitude and Departure. These are given in mathematical tables. A page is devoted to every degree and to every quarter point of the compass. In the first column of each page is given the distance run, and opposite the difference of latitude and departure in nautical miles.

Example: A ship is in lat. 29° 13′ S., long. 104° 29′ E. She sails a distance of 181′ (i.e. sea miles) by log on the compass course 299°. Find her dead-reckoning position (i.e. her new latitude and longitude) from the course and distance. Variation, 17° W.; Deviation, 3° E.

Course by compass ...	299°
Deviation, E. (add) ...	3°
Course, magnetic ...	302°
Variation, W. (subtract)	17°
Course, true	285°, or N. 75° W.[1]

From Tables, differences of latitude and departure, course 75°, distance, 181′: Lat. 46·8 miles N.; Dep. 174·8 miles W.

[1] The tables only give courses up to 90°. Hence they must be reckoned east or west of north or of south, but never north or south of east or of west, for the purposes of the table.

This difference of latitude is equal to 0° 47′ N.,[1] and the ship is therefore in south latitude 29° 13′ − 0° 47′, or 28° 26′.

To find the difference of longitude, recall that the departure corresponding to 1′ of longitude in sea miles is the cosine of the latitude (p. 251). We must therefore divide the departure by the cosine of the latitude, or, what is the same thing, multiply by the secant of the latitude. But we have two latitudes, the initial and final, and are concerned with the difference in longitude between a point in one and a second point in the other. It is therefore better to take the secant of the mean latitude.

Log difference of dep. (174·8)...	2·242 54
L secant mean Lat. (28° 40′) ...	10·056 79
Log D. Long. (in minutes) ...	2·299 33

D. Long., 199′ W., or 3° 19′ W.

Final longitude of ship, (104° 29′ − 3° 19′) E., or 101° 10′ E.

Final dead reckoning position of ship is therefore, lat. 28° 26′ S., 101° 10′ E.

Note particularly that the log only indicates the speed of the ship through the water. Thus, a ship may be doing 15 knots by log on an eastward course through water itself moving 5 knots westward. In this case the speed of the ship would really be 10 knots only. Her longitude (if she were sailing round the equator) would only change at the rate of 10′ per hour. Thus there is always a difference between the dead reckoning position and the position by observation due to current and drift, and the difference provides data for the study of ocean currents (cp. p. 245).

[1] The course takes the ship west of north; that is partly west and partly north. Hence the differences of latitude and departure are north and west.

CHAPTER X

OCEAN TRANSPORT II: INTERNATIONAL TRADE

In mediæval times ocean transport was concerned with the interchange of commodities between Europe and the Orient. Its main avenue led through the Mediterranean. At the Isthmus of Suez there was an overland connection with the sea traffic of the Indies in the Red Sea. Thus, the ancient route was that which at the present day is used for fast traffic with the East. The occupation of the inner end of the Mediterranean by the Turks closed this eastern gateway. But the commerce with the Orient was of prime importance to western Europe. In the severe northern winter there was great dearth of food for man and beast. Modern methods of storing cattle-food were not in use, and in order to prevent animals dying of starvation, the summer herds were thinned down and the meat salted and preserved for winter use. The spices and condiments of the East became essential to the western peoples for use with this preserved meat, and the trade in these was vital. The closing of the inner end of the Mediterranean made it necessary to seek and find other lines of communication with the spice islands, and led to the great voyages of discovery. The search for the North-East and North-West Passages brought no new road to the Orient, but led to the establishment of Archangel and trade with Russia, and to the beginning of the Arctic whale fisheries on the one hand, and on the other to the discovery of the northern part of America. The bold westward project of Columbus was crowned, not with the discovery of new roads

to old sources of supply, but with the discovery of a new world. Only the Portuguese voyages by the Cape led directly to the re-establishment of communication with the Indies.

Ocean transport is the general means of international trade. This trade still depends on the differences in conditions in different regions. First are the differences between the resources of different regions. Some are rich in mineral wealth: South Africa is the main source of gold, mineral oil is found in America and Rumania, tin in the Malay Archipelago; this country, rich in coal, was for many years the chief source of coal supply for the continent of Europe. Plant growth varies with variation of locality, and depends partly on climate, partly on topography, and partly on other things. Steep mountainous regions are not suitable for arable agriculture, and they are often given over to forests and to the lumbering industry for which they are remarkably well suited; we get most of our timber from the desolate and mountainous regions of Sweden, Russia, and North America. Different climates have their characteristic vegetation; from Canada and northern United States we derive large store of wheat, from the southern States most of our raw cotton. Mediæval Britain depended on the sunny Indies for its spices.

Again there are differences in the industrial development of regions. In the early days when settlers were few in America they were confined to the east, and lived by hunting and trapping, and the gathering of the natural products of the forest. Later the eastern States became agricultural as population increased, and the hunting was carried on in the western fringes of settlement. Now hunting has been pushed back into the far north and west, agriculture into the

prairies, and the eastern states are mainly manufacturing. First we imported hides, furs, gums, and herbs from eastern North America. Later wheat was added, and now we obtain from them manufactured goods. This change was accompanied by a change in the density of population. As a country fills up with people it will no longer support them by its own resources; it may not even provide them with sufficient raw material for manufacture. They find their living in transforming goods by manufacture to a condition of very high value. Thus for many years the typical imports of this country have been foodstuffs, raw materials, and partly manufactured goods. Her characteristic exports have been completely manufactured goods whose value has been greatly increased by the work put into them. A great proportion of exports are re-exports. For the most part the *materials* of export are such. We use them as the means of making saleable the value of our capital, labour, and industrial organization. To get our real or *net* exports we must subtract from the gross the value of the raw materials imported. The remainder includes the value of the raw materials the country affords, such as coal, together with the value of the intangible things mentioned. We live as a nation by exporting some of the value of our labour, together with the international services of ocean transport, commercial agency, and credit which we render. The exports of foreign trade of "new" countries are bulky, consisting chiefly of foodstuffs and the raw materials of industry, for the most part almost the direct product of nature. The exports of an old, settled, industrial country are compact, artificial, and of high value.

Lastly there are racial differences. German pro-

ducts have been characterized by their dependence on science; French by taste and skill; curios are products characteristic of different races. More free intercourse and international rivalry are tending to obliterate these racial differences by which one nation produces products saleable to others. Machinery is eliminating differences of artistry, the spread of civilization is removing differences between peoples. New countries are gradually filling up and becoming industrial. The two latter causes of international trade are therefore disappearing, and the first is destined to be the controlling one of the future. It will always be necessary to obtain food and raw material. Countries with available sources of power will tend to be manufacturing, the others will be granaries and suppliers of raw material. China, for instance, has great mineral wealth, and she is destined to become a manufacturing country, although large tracts of her dominions will remain agricultural. She exports at present chiefly food and raw material. Sweden is rich in iron-ore but lacks coal. She is therefore a source of supply of raw material. The same is true of Spain.

This specialization of countries is only made possible by the development of modern ocean trade. The cargo of olden times was an assortment of small amounts of valuable commodities which could bear the expense of long and costly transport. Nowadays a whole ship's cargo may consist of a single cheap commodity brought from the ends of the earth without undue inflation of its selling price. Indeed foreign goods from a great distance may undersell the home product, as American wheat did when it brought about the decline of arable agriculture in this country. On land, roads must be made for

communication, and besides transport and service charges, goods must pay tolls to provide interest on the great capital required to make and maintain railways, and the still greater needed for canals. But the ocean is free; competition is unrestricted, and cities are anxious for their own benefit to provide the terminal accommodation of ports. Modern methods of navigating and propelling ships have enabled man to make full use of the free ocean highway.

The modern tendency is to increase the size of ships. Two ships of small capacity cost more to build and run than one ship of twice the size. The chief limit to size is the size of cargo likely to be obtained. For a time the depth of water available in harbours and channels does restrict the size of ships; but deeper ports are always obtainable: the port authorities are always anxious to grasp an obvious advantage by increasing the depth of water available, and less progressive ports must follow the more advanced on pain of extinction. Increased draught of modern vessels seriously reduced the trade of the port of Bristol to the advantage of Liverpool and other ports, with the result that she has had to improve her harbour and to establish deeper water out-ports at Avonmouth and Portishead. The introduction of mechanical propulsion has reduced the duration and uncertainty of voyages, and it has also reduced the size of crew necessary for the working of the ship. The use of oil as fuel and the development of the internal combustion engine are reducing it still further, relieving the cargo of the cost of wages and men's food.

"Line" and "Tramp" Traffic.—Ocean traffic is of two kinds: "line" traffic, carried on by the regular

liners which make regular voyages on definite routes; and charter traffic, carried on by "tramp" steamers which go wherever cargoes are to be had, and compete for these cargoes on the open freight market. The regular lines are more in the public eye, but the great bulk of the world's traffic is carried by the tramps. They carry especially the large consignments of food and raw material: they can only be employed by the shipper who is prepared to fill a whole ship. When he has a cargo he applies to a firm of ship-brokers. It is the business of these men to watch the world's markets, and to know where cargoes are to be obtained, and, particularly, at what ports a ship may be expected to get a cargo when she has unloaded in the vicinity; for economical transport demands that a ship should always be usefully employed. If she has to proceed from the port of unloading to a distant one for cargo, her freight rates will have to be sufficient to cover the cost of the profitless runs. It will pay a ship's owner to carry any cargo at a very low rate rather than sail his ship empty. For example, many ships are engaged in running wheat in the season from America to this country. The exports from this country are of the nature of manufactured goods. They are not usually sent in consignments of sufficient bulk to warrant charter, and hence travel by liner. Consequently, the ship which brings in the wheat has difficulty in finding a return cargo. It therefore happens that she may carry coal, building stone, or other such material back to the United States although that country is already well provided with these. But rather than carry nothing but ballast, and pay the cost of loading and discharging it, coal is taken at rates so low that it can compete on the American market with the home pro-

duct. Thus it is that the cost of carrying goods the three thousand odd miles across the Atlantic may be less than the railway charges for carrying the same thing a few miles ashore.

These large tramp cargoes are shipped only to one or two great ports in a given country. From these they are distributed by coasting vessels or by rail and canal. But improvement of harbours is leading to the coasting being largely done by the tramps which do the ocean voyage. Centralization of import trade was also brought about by centralization of markets. For example, the South Lancashire district was until recently the main cotton manufacturing district in the world. Thus at Liverpool, and later at Manchester, there was a brisk market for raw cotton. Shippers of cotton, quick to see that in a market where the greatest competition was to be found there was the best chance of good prices, were in the habit of shipping their cotton practically entirely to these places. Buyers again, alive to the facts that it is advisable to buy in a market where a large range of goods may be inspected, and that bargains are more readily to be had in such places, congregated at Liverpool, where was imported almost the whole European supply of raw cotton, to be distributed to the various countries as bought. Such trade is called *entrepôt* trade. London was for long the first entrepôt in the world. This was the natural market for the goods from the extensive British colonies; it was a great financial centre, where capital was available for large deals, and in it gathered the agents of buyers and sellers of this country, the colonies, and foreign lands. Naturally other ports looked covetously on this lucrative trade, and made efforts to capture a share of it; and modern progress

has favoured their efforts, which were directed to the provision of harbour facilities and of coasting vessels. As great manufactures grew up in other countries, great markets on the plan of the cotton market of Liverpool came into being, and such ideally situated ports as Antwerp and Hamburg grew into entrepôts. But decentralization has gone on beyond this point, and the entrepôt trade is still being more distributed, because world markets are becoming international under the influence of the telegraph. As soon as a cargo is on the sea agents are busy at its disposal, and a cargo of cotton may be put up for sale and sold soon after the markets have been advised of its dispatch. The ship will leave Mobile, say, to proceed to Plymouth for orders. The European agent will have been advised of her departure, and sells the cargo, maybe to a dealer in Hamburg. He will wire the signal station at Plymouth, and whenever the ship arrives off that place she will receive instructions to proceed to discharge at Hamburg. Wireless telegraphy is obviating the need even to call at a port for orders. Market reports sent out by telegraph make the maintenance of selling agents unnecessary. The shipper can follow the European markets in his office, and keep in touch with his cargo by wireless until the moment when its destination must be settled. Then he will instruct it to be taken to the market where the best prices are ruling.

Freight Market.—The freight or charter market is as international as the wheat or cotton market, for it is followed by the same means. Hence the freights on cargoes fluctuate enormously. Wheat for example is produced for the international market in both hemispheres and in climates as diverse as

those of Canada, India, and Egypt. The exporting season is therefore different as the harvest time is different in the various wheat countries. Where the wheat is available for export, thither flock the ships. Take Australian wheat. The yield of wheat there is very variable. In a poor season the number of ships available may be much in excess of the cargoes. Hence there will be strong competition for the goods, and freights will fall. In a good wheat year, on the other hand, there will be competition for the ships in order to get the grain to market, and freights will rise. These vagaries in freights, however, are being controlled by the circulation of harvest reports. These the ship-broker studies, and improvements in communication and the organization of trade enable the supply of ships at wheat ports to be regulated in accordance with the supply of cargoes. The fact that liner companies found the competition of the tramp so severe that they instituted regular lines of tramp steamers is at once reducing the number of tramps and stabilizing the freight markets. While the tramps have in their favour the element of speculation, the tendency of the buyers is to require smaller shipments, because they enable them to dispense with the great and increasing cost of storage ashore, and tie up less capital, which is only remunerative while it is "moving"; and the regularity of the sailings of tramp liners with their assorted cargoes of smaller consignments enables them to have prompt deliveries, and, as it were, to live from hand to mouth with safety.

The liners carry passengers and freight on regularly scheduled sailings. They call at several ports, where they collect cargo and deliver it, and their cargo consists of assorted goods. Thus they carry com-

modities which are too small to fill a tramp. Goods of high value, like manufactured goods, and precious articles, perishable goods, and, generally, commodities which are required to be delivered speedily, are their cargo. They are suited to carry the exports of manufacturing regions, the imports of new and agricultural countries, just as the tramps are adapted to carry the bulky imports of manufacturing, or exports of agricultural and new, countries. Like tramps they are often fitted for special purposes: with refrigerating machinery and insulated holds for the carriage of meat and tropical fruit, or they may be built specially for a single trade, like the floating oil-tanks that carry mineral oil in bulk. Their tariff is fixed for each class of goods. It is based on allowing 40 c. ft. of hold space to every ton of cargo. Light bulky commodities therefore pay more on their weight than heavy ones. Differences are also made according to the nature of the goods. Thus, certain manufactured goods are easily damaged and require more careful handling, and their carriage costs more. Explosives, acids, and other goods dangerous to the ship and the rest of the cargo are also subject to higher charges. Freight depends also on the route. Some routes are more dangerous than others, and the insurance on the ship and cargo is higher. This has to be borne by the cargo. On frequented routes there is more competition, and consequently freights are lower. There are also many anomalies in charges. A desire to encourage a particular traffic for the cultivation of trade may be the cause of a lower charge for certain commodities, and the special charge tends to linger after the need for it has passed. Any consignment, moreover, may be sent on a specially quoted charge, and changes are

continually being made on the representations of shippers, often based on precedent or charges for goods of similar kinds.

Ocean Routes.—The prime factor which determines the course of the ocean routes is the fact that the great circle joining two points offers the shortest way between them. While the great circle is the pattern route, it is modified by certain considerations already referred to in other chapters. In addition to these there are two special points to take into consideration. Liners in particular obtain their trade from more than one port. They make a regular round of sufficient ports to give them full cargoes and complements of passengers. Thus, the Australian lines which sail by Suez call at Colombo and sometimes Bombay, and the Australian ports of Fremantle, Adelaide, Melbourne, and Sydney. Passengers often prefer overland travel as far as possible: hence these lines call at Marseilles. Mails are also sent overland as far as possible for the sake of speed. European mails for the East are sent overland to Brindisi, but instead of calling there, it is found preferable to have a subsidiary sea service thence to Port Said, and the liner picks up the mail bags at the Suez Canal ports, where she is bound to stop. The other point is the question of fuel. Coal, as we have seen, is a cargo suited to the tramp traffic: it requires the lower rates for carriage, not speedy delivery. The hold space of the liner is more valuable than that of the tramp, but she must carry a certain amount of coal. Every ounce of bunker coal she carries, however, means that some of her valuable carrying power is put to the base use of that of the tramp, and does not yield full value. But the smaller her bunkers the smaller her range: the shorter the

passages she can make without refilling them. Hence the economic justification of coaling stations, places at which she can fill bunkers. These coaling stations are supplied by tramps, and at them the liner can coal frequently on her voyage. Although she pays more for Welsh coal at Aden than she does at Cardiff, the additional freight she is able to earn by carrying more cargo and less coal from England does more than make up the loss. Her course is therefore determined in part by the situation of the coaling stations. The question of coaling stations is important in relation to the route followed where there is a choice between a canal route and a purely ocean route. If the margin in favour of one route is not great, the question of the frequency of coaling stations may turn it against the otherwise preferable one. The Suez Canal route to the East, for example, is very well provided with coaling stations, as compared with those by the Cape and by Panama (see further pp. 276–9). The introduction of oil fuel will perhaps minimize the importance of coaling stations. Coal in bunkers takes up some of the most useful space of the ship, because it, like cargo, must be easily accessible. But there is a certain amount of waste space in ships in odd angles and corners, some of which is occupied by ballast tanks. Since the oil is led to the stokehold in pipes it does not matter where in the vessel it is carried, and the oil tanks can be built in just those spaces that at present are waste; and more oil may be carried in the ballast tanks, which, when empty, are completely useless. Thus the bunker and cargo capacity of ships may both be largely increased by the use of oil, and the dependence of ships on coaling stations reduced. The use of internal combustion engines also saves space

Fig. 121.—Map of North Atlantic on Sanson-Flamsteed Projection, to

Scale 1 : 90,000,000

NOTE.—Distances east and west are shown correctly. Distances of any point from any paral
parallels, are also correct. Only on the meridian of 40 W. are the directions of north anc

Great Circles (1) English Channel to New Orleans —.—.—.—.
(2) English Channel to Colon —....—....—....

Great Circles (3) Straits
(4) Straits

Trade Routes ————————

Normal Limit of Drift Ice

for carrying purposes, because they do away with the large stokeholds and boilers required with steam-engines, oil- or coal-burning.

North Atlantic Trade.—The most important ocean trade is the North Atlantic traffic: it is the largest, has the most competition, largest ships, and best service of all. The most striking point about the routes is the closeness of them (fig. 121). Take the great circle from Scotland to New York. It passes practically along the coast of the United States, as the student may show by drawing it on his globe. Thus ships trading to the Canadian ports and those of the Gulf (of Mexico) sail practically within sight of each other. There are few obstructions in mid ocean, and the chief digressions from the great circle are due to the fogs and ice of the Newfoundland banks, and to the shallowness of the banks off Cape Hatteras. Fuel is abundant on both sides, ports on the west side are numerous, and the traffic spreads out to them, for decentralizing causes have reduced the pre-eminence of New York, though not the volume of its trade. On the east the routes converge on the English Channel and to a less degree on the Mediterranean, which lead to the harbours. The main westward movement is in passengers and certain classes of manufactured goods, the eastward trade is grain, raw material, particularly cotton, and manufactured goods of all sorts, but chiefly machinery. Trips in ballast or part cargo are therefore commoner on the former passage, and on it freights are lower.

Pacific Trade.—The Pacific trade passes by the Mediterranean, the Cape, and the Horn. It is also developing by the Panama Canal, and so increasing the volume of the North Atlantic trade. A great deal of American Atlantic, Gulf, and Pacific trade is done

by coasting steamers from central points on the American coast.

The question of the influence of the two great canals is of interest here. That of the Suez Canal is well known: that of the Panama is still indeterminate, but will be determined by similar considerations.

Canal traffic is always more costly than ocean traffic for many reasons. Thus, the Panama Canal cost some £80,000,000 to complete, including payments for the canal zone and other outlays. Interest payable on this amount, say at the rate of 3½ per cent, makes an annual charge on its proceeds of nearly £3,000,000, or over 6*s*. per ton on the tonnage of nearly 7,000,000 which passed through it in 1919. To this must be added the due proportion of the cost of upkeep and management, and of the yearly payment by the canal to the State of Panama, in order to arrive at the toll necessary to be levied to make the canal a paying concern. As a matter of fact the average toll was under a dollar, say 3*s*. 4*d*. This does not include the freight or cost of carriage in the ship. The risks to the ship in canal navigation are greater than on the high seas, and the cost of insurance of ship and cargo is therefore higher. These additional costs have to be set against the loss of time (and earning capacity) involved by a longer route, together with the greater cost of coal and food and wages entailed by longer passage. Let us assume that a ship of 8000 tons has the choice of the canal or a longer route. Her tolls will amount to some £1400, her total additional outlays to, say, £2,000. She will use the canal if it saves for her in time, fuel, wages, &c., a sum not less than that. If she carries passengers or express cargo she will use it even

if it saves her much less, because she can charge higher rates. Tramps do not as a rule carry express traffic, and they will only use the canal if it pays them otherwise to do so. This will depend on the importance of saving time. If trade is brisk, time has a higher value for the tramp, because freights are higher. Tramp traffic on the canal will therefore vary. It may be said at once that, in general, trade to Pacific America will pass by the canal. The saving in distance from Liverpool to San Francisco is over 3500 sea miles, to Valparaiso over 1500 miles. Liners doing 15 knots therefore save 10 days and 4 days, tramps doing 10 knots, 15 and 6 respectively. For the European trade with Asia, the Suez route is the shorter, but the Panama route saves American steamers to ports beyond the Malay Peninsula up to 4000 miles. Wellington, New Zealand, is nearly 2000 miles nearer Liverpool by Panama than by Suez, and lines are already following this route. As to Australian traffic, there is little in it as far as Sydney is concerned, the Suez route being shorter by 300 miles; but the balance in favour of Suez is nearly 2500 miles for Adelaide. New York and Australia are closer by Panama: the differences are 1700 miles for Adelaide, and nearly 5000 for Sydney (cp. tables on pp. 278–9).

Asiatic Trade.—The nature of the trade with Asiatic countries will have an interesting effect on the canal question. These have a fairly bulky import trade from the older countries, but the exports are small. Hence we shall no doubt see a revival of the round-the-world trading voyages. Ships will sail eastward by Suez, cross from Asia to America, as they have done in the past, to fill up with cargo; but instead of returning by Suez

TABLE OF DISTANCES ON GREAT CIRCLE COURSES IN STATUTE MILES

	Route.			
	Cape.	Horn.	Suez.	Panama.
London to Bombay ...	10,900	—	6,200	—
,, Colombo ...	10,400	—	6,600	—
,, Singapore ...	—	—	8,150	—
,, Shanghai ...	—	—	10,450	14,620
,, Yokohama ...	—	—	11,180	13,040
,, Sydney ...	12,660	—	11,600	12,205[1]
,, Wellington ...	13,160	11,970	12,870	10,900
,, San Francisco	—	12,000	—	8,100
,, Valparaiso ...	—	9,000	—	7,420
New York to Yokohama ...	—	—	14,000	10,200
,, Sydney ...	—	—	14,400	9,000
,, Wellington ...	—	—	15,670	8,070
,, San Francisco	—	12,000	—	5,290
,, Valparaiso ...	—	8,300	—	4,600

[1] Calling, as usual, at New Zealand: distance direct, 11,800.

they will continue through the Panama Canal, saving time, and benefiting by the abundant supplies of American bunker coal. This will apply to liners rather than tramps; for the latter carry full cargoes to one port, the former call at many ports, partly discharging and partly taking in cargo at each.

As to the Suez Canal, it is longer than the Panama, some 100 miles against 35, but the tolls levied are only about 5*s.* per ton. It has shortened the eastern routes generally, but the greatest savings are in voyages to the Arabian and Indian waters. That it has by no means monopolized the eastern trade is seen in the great bulk of traffic which still holds to the Cape route. It has the disadvantage that its depth is only some 34 ft., and it cannot accommodate ships drawing over 30 ft., whereas the Panama Canal is

NATIONALITY OF VESSELS USING THE CANALS IN YEAR 1918–9

Nationality.	Suez.		Panama.	
	Number.	Percentage of Total.	Number.	Percentage of Total.
British	697	56	623	31
United States ...	3	—	839	42
Norwegian ...	24	2	124	6
Swedish	15	1	—	—
Danish	11	1	74	3
French	74	6	96	5
Italian	141	11	—	—
Spanish	11	1	—	—
Greek	95	8	—	—
Dutch	1	—	16	—
Japanese	158	13	75	4
Chilian	—	—	78	4
Peruvian	—	—	61	3
Others	11	1	89	4
Total	1241		2075	

41 ft. deep at the shallowest. The Suez Canal has been assisted by the rich provision of coaling stations along its route. It has had the effect of reviving the importance of Mediterranean ports which decayed relatively after the Turkish occupation of the Levantine lands.

Local Trade.—Local trade, although less picturesque than long-distance trade, is of great moment. For instance, there is a vast coasting trade in Australasia. Large steamers, fit for cross-ocean traffic, sail between Australian and New Zealand ports. This type of trade is stimulated and even carried on by the great world-lines; it is necessary to them as providing feeders for the great trunk

runs. There is a modern tendency for companies to serve more than one type of trading route, which is seen in the frequent combining or even amalgamating of several companies. The Cunard Company no longer devotes itself to the North Atlantic trade. It has absorbed several other lines, and has really grown into a British shipping combine. The advantages are clear. Stagnation on a single route due to poor crops, labour trouble, or any of the many possible causes would be very serious for a company which devoted itself exclusively to it. There is always a seasonal variation in trade: after harvest time from a country exporting grain or vegetable raw material, trade is brisk; but it gradually declines and becomes insignificant for the rest of the year. The charter vessel is free to follow the freights, but the tramp liner dare not neglect its route for a season. The company operating on several routes can depend on its busy routes when others become dull, and can keep vessels moving from route to route to supplement the regular service on any which is enjoying its season of prosperity. As ships on first-class routes and services become obsolete they can be transferred to second- or third-class routes; and, last and most important, co-operation between the routes can be secured, so that the benefits of through booking to all parts may be offered, and one branch may act as feeder to the rest. British shipping particularly is not wholly occupied in direct British trade. Nearly a quarter of it is permanently in foreign waters, much of it serving purely foreign subsidiary routes. The Hamburg-Amerika likewise did a great deal of local trade entirely in distant waters.

APPENDIX

The following examples, worked and unworked, are intended not only to afford the student practice and to give him greater familiarity with the work, but also to induce him to go a little farther than space in the text allowed. A certain amount of mathematics is required, but there is no reason to be afraid of it. The student is strongly advised to go through all the examples patiently and conscientiously, to keep his solutions tidy and orderly, to write down all conclusions he may reach, and to preserve the complete record for further use; as, for example, in revising the work. Let him not be too eager to have recourse to the answers. Most of the work is self-checking, and there is more joy and profit in reaching *practically* the same result by two or more methods than in working for a slavish concurrence with the results of other people.

CHAPTER I

1. A boy is lying on the bank at one side of a fair-sized lake or bay, with his eye at about the level of the water, and looking at a post fixed within the water's edge on the other side. How much of the post will he see, and how may he gain a view of all of it? Draw a diagram to illustrate your answer.

2. You are provided with a long stake, across which are painted successive black and white bands 6 in. wide, and sent to such a lake or bay as that in question 1 to prove the earth is curved in north and south and east and west directions. How would you proceed? If you had a pair of field-glasses so that you could see clearly the stripes across the stake, how would you form an estimate of the amount of the curving? (This is a field exercise the student might actually attempt.)

3. A sailor is standing on the deck of a liner which is 65 ft. above the sea-level, and his height is such that his eye is 5 ft. above the deck. He is just able to see a boat on the horizon, and beyond it the top of a lighthouse 100 ft. high. Find his distance from both. (Draw a circle, centre O to represent the *great circle* in whose plane is his line of sight. Let P be the position of the ship on this great circle. Join OP and produce it to E, so that, OP being the vertical, E will represent the position of the sailor's eye. PE will be 70 ft. in this case: call it h for short. Through E draw EB tangent to the circle. Then B will be the most distant point the sailor can see, and it will therefore be the position of the boat. Produce EB to L, and draw OL, cutting the circumference of the circle in Q. Then if QL be 100 ft. on the scale of the diagram, L will be the top of the lighthouse. Call QL h', the radius of the great circle, and therefore of the earth, R, and the angles POB, BOQ, α_1 and α_2 respectively. Then $\cos \alpha_1 = R/(R+h)$, $\cos \alpha_2 = R/(R+h')$. Hence we find α_1 and α_2, and, knowing that 1° of a great circle corresponds to 69·15 statute miles, the lengths of the arcs PB, PQ, the distances of the boat and the lighthouse from the ship.)

4. What are the distances of the apparent horizon at sea of men whose eyes are 5, 20, 30 ft. respectively above sea-level? What is the radius of the small circle of the horizon in each case? (EB in the figure drawn for last exercise, the line of sight, sweeps out the curved surface of a cone as the eye sweeps round the horizon; it does not remain in the same plane. BM, perpendicular to OE, is the radius of the circular base of this cone, the apparent horizon. Why?)

5. Find the radii of the parallels of 29° N., 37° S., 61° N. Find also the length of these parallels, and the distance along each equivalent to 1′ of longitude, all in statute miles.

6. New Orleans and Cairo (Egypt) are both in lat. 30° N. Their longitudes are respectively 90° W. and 31° 17′ E. Find their distance apart, measured along the parallel in statute miles.

7. Ottawa is in lat. 45° 20′ N. Find to the nearest minute the latitude of a place 2423 statute miles due south of it, and find in your atlas the town nearest the position.

8. On a sufficiently large sheet of cardboard draw a circle of the same radius as a terrestrial globe to which you have access. Lay off round the outside of the circumference of this circle a scale of degrees, exercising great care, and subdividing each degree if the circle is large enough. Cut out the circle, and by

means of the ring left measure the great circle distances (in angle) from London to (1) New York, (2) Yokohama, (3) Sydney (N.S.W.), (4) Cape Town, (5) Panama, (6) Buenos Aires, and convert these distances into statute and nautical miles. Measure also the great circle distance from Cairo to New Orleans, compare it with that found in question 6, and explain any difference.

9. Using the ring of last question, draw, and write a list of the chief places near, the great circle from London to Perth, West Australia.

Answers—

3. 9, 20 nautical, $10\frac{1}{3}$, 23 statute miles.
4. $2\frac{3}{4}$, $5\frac{1}{2}$, $6\frac{3}{4}$ miles; radii same.
5. 3460, 3160, 1918; 21,740, 19,852, 12,051; 1·01, 0·92, 0·56 statute miles.
6. 7263. 7. 10° 18′ N.

CHAPTER II

1. From your atlas write lists of:
   (1) The chief places in the British Isles approximately due north and south of London, Edinburgh, Exeter, and Belfast.
   (2) The chief places in Europe nearly due south of Hull, and nearly due east of London and Bordeaux.
   (3) The chief places in North America due west of St. John, New Brunswick, and due north of New York and San Francisco.

2. From your globe or atlas read the longitudes of Killarney, Chicago, Vancouver (B.C.), Santiago (Chile), Poona, Tokyo, Hong-Kong, Christchurch (N.Z.), and find the local time of Greenwich noon at each.

3. Determine as accurately as possible by means of your globe and the cardboard circle (Chapter I, question 8) the latitudes of the places given in last question, and find the altitude of the sun at each at local apparent noon at the equinox and at the winter solstice.

4. Captain Scott died in lat. 79° 40′ S. on 27th March, 1912, when the sun would be in declination 2° 34′ N. Find the altitude of the sun there at noon on that day, and determine whether it would be above the horizon or below at midnight, and how much.

Draw an accurate figure to illustrate your answer, and compare your calculated angles with those measured from your figure.

5. Find the latitude of Hammerfest from your globe, and by means of the *Nautical Almanac* determine the period during which the sun is above the horizon throughout the twenty-four hours, and below the horizon continually. How does the sun behave at other times there?

6. On midsummer day the shadow of the upright or style of the gnomon is half as long again as the style. Find the latitude of its situation.

7. The following observations were taken at a place north of the equator:

Greenwich Time of Observation.			Altitude of Sun.		
Hr.	Min.	Sec.	Deg.	Min.	Sec.
21	08	14	38	46	30
	12	36		47	15
	17	04		47	55
	20	56		47	50
	25	00		47	00
	27	45		46	20

Declination of sun, 13° 21′ 06″ N.

Find the latitude and longitude of the place, and locate it. (By means of a graph find the amount and time of maximum altitude, and use these to find the latitude and longitude by the methods on pp. 38, 54. The method is a rough one, but gives latitude better than longitude. Why?)

8. Theodolite observations of α *Tauri* (Aldebaran) near its southern (upper) transit (declination, 16° 20′ 15″ N.).

L.M.T. of Observation.			Reading on Vertical Circle.			Reading on Horizontal Circle.					
						On Star.			On R.O.		
Hr.	Min.	Sec.	Deg.	Min.	Sec.	Deg.	Min.	Sec.	Deg.	Min.	Sec.
7	34	30	67	42	30	84	56	15	3	19	20
	39	00		43	25						
	43	00		44	05						
	47	00		44	10						
	50	30		43	35						
	54	00		42	15	176	01	00	94	23	30

Find the latitude of the place at which the observation was made and the bearing from it to the R.O. Is the observation sufficient for finding the longitude? If the L.M.T. chronometer is 6 hr. 01 min. 12 sec. slow on G.M.T., what would be the longitude, and where would the place be? If the observation referred to an upper transit to the north, what would be the latitude of the place?

9. Make a table showing the altitude of the sun at the equinoxes on each parallel of latitude. Do the same for the summer solstice.

10. Find the extreme errors of standard time on L.M.T. on the margins of the time zones in fig. 29. (E.g. Atlantic time, 4 hours slow on Greenwich, is used at St. John's, Newfoundland, which is in long. 52° 54′ W. In this longitude L.M.T. is 3 hr. 31 min. 36 sec. slow on Greenwich, and therefore standard time is 28 min. 24 sec. slow on L.M.T.)

11. A telegram from London was marked as despatched at 10.15 a.m., and as received at 5.13 a.m. Assuming that ten minutes were occupied in transmission, and that L.M.T. was used at the place of receipt, find the longitude of that place.

12. A traveller assumes the Pole Star to be at the celestial pole, and from its altitude concludes he is in lat. 45° 17′. He makes a solar observation next day, and this shows his latitude to be 44° 08′. Explain the discrepancy. Find the declination of the Pole Star. If the latitude by the star had been 44° 50′, what would have been the reason? What must you assume in finding the declination? Is the latitude north or south?

Besides working these examples, the student ought to make observations for time, longitude, azimuth, and latitude with such instruments as may be available. If he cannot have the use of a theodolite or sextant, a simple theodolite or clinometer may be used for practice, though they will not give very close results. Failing other apparatus, he should make and use a gnomon. The observations ought to be repeated on several days at the same point, the several results tabulated, and estimates made of the amount of error to which they are liable.

Answers—

2 and 3. 52° 03′ N., 9° 30′ W.; 42° 50′ N., 87° 37′ W.; 49° 30′ N., 123° 00′ W.; 33° 36′ S., 70° 30′ W.; 18° 31′ N.; 73° 55′ E.; 35° 40′ N.; 139° 48′ E.; 22° 16′ N., 114° 09′ E.; 43° 30′ S., 172° 30′ E. 11.22 a.m., 6.09 a.m., 3.48 a.m., 7.18 a.m.,

4.56 p.m., 9.19 p.m., 7.37 p.m., 11.30 p.m. Altitudes are equal to co-latitudes at equinoxes, and to 23° 27′ less at winter solstice.

4. Noon, 7° 46′ above horizon; midnight, 12° 54′ below.
5. Lat. 70° 40′ N.; sun continually above horizon from about 16th May till 26th July, and below from about 18th November till 23rd January; at other times sun rises and sets daily.
6. Lat. 79° 45′ N. or S.
7. Archangel, 64° 33′ N., 40° 33′ E.
8. St. Louis, Missouri, U.S.A., 38° 36′ N., 90° 18′ W.; bearing, 98° 23′; lat. 5° 56′ S.
11. 78° W.
12. Declination, 88° 51′ N.; lat. N.

CHAPTER III

1. What is a map projection, and of what use is the graticule which appears on atlas maps?

2. Examine the maps in your atlas, and decide which projection is used for each. Write down your opinion, and the reasons on which it is based. Consider in each case the reasons for which the particular projection has been chosen, and suggest alternative or better projections.

(E.g. map of Norway and Sweden; parallels arcs of concentric circles, which seem to be equally spaced; meridians straight lines, converge northwards to a point beyond lat. 90°, which is the centre of the arcs. The projection is the simple conical, and will have one or two standard parallels according as the scale along the parallels about the centre of the map is less than or equal to that along the meridians; but the scale of the map may be too small to allow of the necessary measurements being made).

3. Construct a simple conical graticule with one standard parallel for a map of the United States on the scale of 1:30,000,000. Insert six places on or very near the standard parallel, and six on the central meridian, and sketch in the outline from your atlas. Put arrows to indicate east winds blowing at Los Angeles and Newhaven, Connecticut, and north winds at Detroit and Seattle.

4. Construct on tracing paper a Mercator map of the same area as in question 3, such that the parallel selected as standard

in that question shall be of the same length on both maps. Mark in the same places and winds, and try to fit the second map to the first. Explain the difficulty of fit, and compare the two maps generally.

5. Construct on Bonne's projection maps of Europe on the scale of 1 in 30,000,000,

(*a*) with central meridian that of Greenwich;
(*b*) with the straight meridian that of Petrograd, the map being drawn on tracing paper.

Fit the second map to the first and compare them.

6. Draw a map of the north polar regions on the zenithal equidistant projection to any suitable scale, and insert the routes followed by the chief explorers.

7. Draw a map of the south polar regions on the stereographic projection, compare it with that in your atlas, and also with the representation of the same region on the map of the world on Mercator's projection.

8. On your atlas map of the world on Mercator's projection measure the length of the equator, and determine the R.F. Measure the distance between successive parallels on any meridian, and between any two successive meridians on each parallel. Multiply these by the R.F. already determined to find the distances they represent on the scale of the equator. Put these results in a table, write against each the corresponding distances on the earth (Tables I, II, pp. 8, 15), work out the exaggeration in scale for each, and add these to the table. What are the facts brought out? (Cp. pp. 63–4 and fig. 34.)

9. On what projections are the climate and vegetation maps of the world in your atlas? Would you use the same projection for maps to show winds and currents on the one hand, and rainfall and vegetation on the other? Cylindrical projections are very common for such maps. Are they always or ever the most suitable?

10. A map of Australia is required on the scale of 1:20,000,000. Select a projection, give your reasons for the selection, and construct the map.

11. Trace carefully from your atlas the map of the world on Mercator's projection. If the parallels are drawn at intervals of more than 10 degrees, insert the parallels of 10, 20, 30 . . . degrees. If not, insert parallels every 5° N. and S. of the equator.

12. Construct a graticule for a map of the world on Mollweide's projection, selecting such scale as will make the equator about 15 inches long, and inserting meridians and parallels every 10 degrees.

This useful projection is not hard to construct. The graticule is contained within an ellipse whose major axis is twice the minor. In fig. 122 NFSG is the ellipse, and the circle NHSK, half the ellipse in area, represents a hemisphere. If R is the radius of the globe, then r the radius of the circle is $\sqrt{2}R$, since the projection is equal area (see p. 73). The circle having

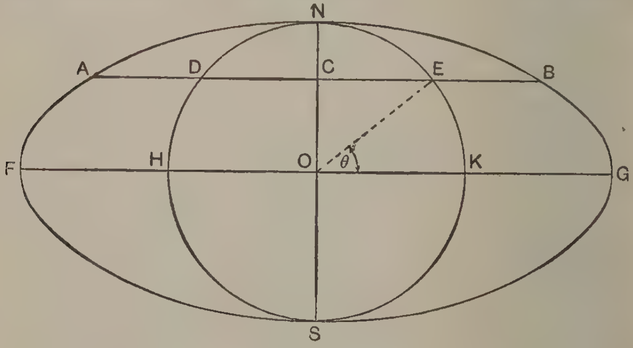

Fig. 122

been drawn, the parallels are to be put in, and this is the hardest part of the problem, since they must be at such distances apart that the projection shall remain equal area.

In the figure, let AB be the parallel of latitude ϕ, and call the angle EOK θ. As on p. 84, the area between the parallel of latitude ϕ on the globe and the equator is $2\pi R^2 \sin \phi$. This must be equal to the area AFGB on the projection, which is twice DHKE; and DHKE is twice the triangle OCE together with twice the sector OKE. Now,

$$\begin{aligned} \text{area of OKE} &= \frac{\theta^*}{2\pi}\pi r^2 \\ &= \tfrac{1}{2}r^2\theta; \\ \text{area of OCE} &= \tfrac{1}{2}r \sin \theta .\ r \cos \theta \\ &= \tfrac{1}{4}r^2 \sin 2\theta; \\ \text{and so, } \pi R^2 \sin \phi &= r^2\theta + \tfrac{1}{2}r^2 \sin 2\theta = 2R^2\theta + R^2 \sin 2\theta. \\ \therefore\ \pi \sin \phi &= 2\theta + \sin 2\theta. \quad\ldots\ldots\ldots\ldots (1) \end{aligned}$$

* θ in circular measure.

Also, the distance on the projection of the parallel from the equator is OC, and OC ($= x$) $= r \sin \theta = \sqrt{2}R \sin \theta$.

It is not easy from (1) to calculate θ having given ϕ, but from θ it is easy to calculate ϕ and x. For example, let θ be 10 degrees, and let the R.F. be 1:10,000,000, so that R is 25·065 in. (see question 16, *b*).

Then, $\theta^* = \underline{0·1745}$ from tables	log 2 $\underline{0·3010}$
$2\theta = 0·3490$	log $\sqrt{2}$ 0·1505 (half log 2)
$\sin 2\theta = \underline{0·3420}$ (not L sin 2θ)	log R 1·3991
$\pi \sin \phi = \underline{0·6910}$ (sum)	L sin θ $\underline{9·2397}$
$\log \pi \sin \phi = 9·8395$	log x $\underline{\underline{0·7893}}$ (sum)
$\log \pi = \underline{0·4971}$	$\underline{\underline{x, 6·16 \text{ in.}}}$
$\therefore$ L sin $\phi = \underline{\underline{9·3424}}$ (difference)	
$\underline{\underline{\phi, 12^\circ 43'}}$	

Parallels are to be drawn every 10° of latitude, and so x and ϕ must be calculated for $\theta = 5°, 10°, 20°, \ldots 90°$. Then the calculated values must be plotted against each other on squared paper, and a graph drawn from which the values of x can be read for the required values of ϕ. The proper values of x having been laid off along NS, the parallels are drawn as straight lines parallel to FG, and the portions of them beyond the circumference of the circle are made equal to the portions between the circumference and NS. A smooth curve drawn through the ends of the parallels gives the ellipse, and the parallels having been divided into thirty-six equal parts, smooth curves joining corresponding points of division are the meridians.

13. By the method of question 8, p. 284, draw on your globe the great circle passing through Tokyo and New York. Read off as accurately as you can the latitudes in which the circle cuts the meridians on the globe, and write them in a table. From the table plot the great circle on the maps of the last two questions.

14. On the above maps measure the distance across Asia from Tokyo to New York (*a*) along the straight line joining them on the map, (*b*) along the great circle as drawn, assuming in either case that the scale is the same as along the equator. Measure also the great circle distance from the globe. Set out the results for comparison in a table, and write down your conclusions as to

the distortion of the maps. Is the distance as measured on the maps along the great circle the shortest distance?

Great circles being of importance here and in Chapter IX, we proceed to show how they may be followed accurately and plotted on maps.

Each great circle cuts the equator in two points called *nodes.* It is shown in books on analytical solid geometry that for points in a plane passing through the centre of the sphere,

$$\tan \phi = \tan \alpha \sin \lambda,$$

where α is the angle between the plane and that of the equator, and ϕ is the latitude in which the great circle cuts the meridian of longitude λ, *the longitude being reckoned from one of the nodes.* Great circles may be traced by means of this formula. Suppose we wish to trace that passing through two points, latitudes ϕ_1 and ϕ_2, and longitudes λ_1 and λ_2. We must first calculate α. To do this write the formulæ for the two points,

$$\tan \phi_2 = \tan \alpha \sin \lambda_2,$$
$$\tan \phi_1 = \tan \alpha \sin \lambda_1.$$

Dividing the one by the other, $\dfrac{\tan \phi_2}{\tan \phi_1} = \dfrac{\sin \lambda_2}{\sin \lambda_1}$.

To save writing, put $m = \tan \phi_2 / \tan \phi_1$. If l is the difference of longitude, which is known, though the longitudes with reference to the nodes are not known, then $\lambda_2 = \lambda_1 + l$, and for $\sin \lambda_2$ we may write $\sin (\lambda_1 + l)$; and it is easy to show that

$$\sin \lambda_1 = \frac{\sin l}{\sqrt{m^2 - 2m \cos l + 1}}.$$

From this we may find λ_1, thence λ_2, and finally α.

Example.—Trace the great circle passing through London (51° 32′ N., 0° 05′ W.) and New York (41° 06′ N., 74° W.).

To find m, λ_1, λ_2—

L tan ϕ_2 (41° 06′)	... ...	9·940 69
L tan ϕ_1 (51° 32′)	... ...	10·099 91
Difference = log m	... ...	9·840 78
L cos l (73° 55′)	... ...	9·442 53
Log 2 ...	... ...	0·301 03
Sum = log $2m \cos l$ ...	...	9·584 34

Log m^2	... ...	9·681 56 (twice log m)
m^2	... ...	0·480 35
$m^2 + 1$	... ...	1·480 35
$2m \cos l$	... ...	0·384 01
$m^2 - 2m \cos l + 1$	...	1·096 34

Log $(m^2 - 2m \cos l + 1)$	... ...	0·039 94
Log $\sqrt{m^2 - 2m \cos l + 1}$	...	0·019 97
L sin l	... ...	9·982 66
Log $\sqrt{m^2 - 2m \cos l + 1}$	... ...	0·019 97
Difference, L sin λ_1	... ...	9·962 69

$$\therefore \lambda_1 = 66^\circ\ 35', \text{ and } \lambda_2 = 66^\circ\ 35' + 73^\circ\ 55' = 140^\circ\ 30'.$$

[Clearly, the great circle will not cut the equator on the Atlantic between London and New York; hence, λ_1 is in west longitude with respect to the node, and the node is $(66^\circ\ 35' - 0^\circ\ 05')$ east of Greenwich.]

To find α—

From the original formula $\tan \alpha = \tan \phi_1 \operatorname{cosec} \lambda_1 = \tan \phi_2 \operatorname{cosec} \lambda_2$.

L tan ϕ_1 ...	10·099 91		L tan ϕ_2 ...	9·940 69
L cosec λ_1 ...	10·037 33		L cosec λ_2 ...	10·196 49
L tan α ...	10·137 24			10·137 18

The reason for working out L tan α in duplicate is to check the work. The discrepancy between the values here is 6 in the last place of decimals, and is due to the fact that we have not worked to seconds. If the difference had been large, we should conclude that there was an error in the calculations, perhaps right at the beginning. It is not necessary to perform the calculation in the form adopted, but it is best to have some set regular form for working all such examples. Since we work with tan α in using the formula, it is not necessary to look up the angle itself: the log of the tangent is all that is required.

In order to trace the circle we must calculate the longitude in which it cuts selected parallels, or the latitude in which it cuts selected meridians.

(1) *Parallel of 60° N.*: $\phi = 60°$. *Parallel of 30° N.*: $\phi = 30°$.

	Parallel of 60°	Parallel of 30°
L tan ϕ	0·238 56	9·761 44
L tan α	10·137 20	10·137 20
Difference, L sin λ	10·101 36	9·624 24
		λ, 24° 54′.

There is no angle whose sine has a log greater than 10, and hence the circle does not cut the parallel of 60°. Indeed, it is at once clear that the most northerly point (or southerly) on the great circle has latitude equal to α, that is 53° 54′ half way in longitude between the nodes. Also, the circle must cut any parallel *twice*, on meridians equally distant from either node. It will therefore cut that of 30° N. in long. 24° 54′ W. and (180°—24° 54′) W. Since the node we are considering is in long. 66° 30′ E. of Greenwich, these meridians are in 41° 36′ E. and 88° 36′ W. of Greenwich. Lastly, the circle will cut the meridians 180° from these in 30° S.

(2) *Meridian of 50° W.* *Meridian of 150° W.*

Longitudes referred to node are—

	Meridian of 50° W.	Meridian of 150° W.
λ =	116° 30′ W.	216° 30′ W. (143° 30′ E.)
L tan α ...	10·137 20	10·137 20
L sin λ ...	9·951 79	9·774 39
L tan ϕ ...	10·088 99 (sum)	9·911 59
	ϕ, 50° 50′.	39° 12′.

As before, the meridians of 50° W. and 3° E. will be cut by the great circle in lat. 50° 50′ N., and those of 130° E. and 177° W. in lat. 50° 50′ S., those of 150° W. and 103° E. in lat. 39° 12′ S., those of 30° E. and 77° W. in lat. 39° 12′ N.

Construct a gnomonic graticule for the Northern Hemisphere, and by means of it check the great circle (a straight line on the graticule).

15. Complete the calculations for the great circle from London to New York. Plot the circle on the globe from the calculated results, and check them by means of the paper ring.

16. Calculate for maps on (*a*) simple conical projection, with standard parallel that of 40° N., and central meridian that of Greenwich; (*b*) Mercator's projection, the distances in inches

"north" of the parallel of 40° N., and "east" of the meridian of Greenwich, of the places given below. Scale 1:10,000,000. Check the results by means of the maps in your atlas.

	Latitude.		Longitude.
Londonderry ...	... 55° 00′ N.	......	7° 20′ W.
Vilna ...	... 54° 55′ N.	......	25° 00′ E.
Lisbon ...	... 38° 42′ N.	......	9° 08′ W.
Tromsö ...	... 69° 50′ N.	......	18° 32′ E.
Berlin ...	... 52° 45′ N.	......	13° 24′ E.
Corinth ...	... 37° 55′ N.	......	22° 53′ E.

Example.—Danzig, 54° 22′ N., 18° 39′ E.

(*a*) *Mercator's Projection*—

Meridional parts	54° 22′	3,902·2 (geographical miles)
,, ,,	40° 00′	2,622·7
Difference ...	...	... 1,279·5

Reducing this to inches (taking 6080 ft. to the geographical mile), and reducing to scale, distance x north of the parallel of 40° N. on map is

$$\frac{1279\cdot5 \times 72{,}960}{10{,}000{,}000} \text{ in.} = 9\cdot33 \text{ in.}$$

Longitude from meridian of Greenwich = 18° 39′ = 1119′.

On Mercator's projection the minute of longitude is of the same length on every parallel as on the equator, hence y, the distance east from meridian of Greenwich, is

$$\frac{1119 \times 72{,}960}{10{,}000{,}000} \text{ in.} = 8\cdot16 \text{ in.}$$

To check on the student's map, it is necessary to measure the length of the equator, or say 90° of it, in order to find the scale there. Suppose it is 1:125,000,000, the distances obtained above must then be divided by 12·5, when they should agree with those measured from the map.

(*b*) *Simple Conical Projection.*—Take radius of the earth as 3956 statute miles. Then R, radius of globe on scale 1:10,000,000, is

$$\frac{3956 \times 63{,}360}{10{,}000{,}000} \text{ in.} = 25\cdot065 \text{ in.},$$

and r_0 = R cot 40° = 29·872 in. (see p. 79.)

Parallel of Danzig is 14° 22′, or 862′, or 862 geographical miles north of that of 40°, and this on the scale of the map is 6·289 in. Hence, for this parallel, r = (29·872—6·289) in., or 23·583 in.

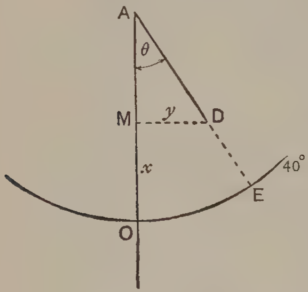

Fig. 123

Since scale along standard parallel is true, we can calculate the size of the angle θ (see fig. 123), for its circular measure is arc OE/AE. Arc OE is 18° 39′ on the parallel of 40° N. where the degree of longitude is 53·06 statute miles (Table II, p. 15). Hence length of arc OE on map is ($18\frac{39}{60}$ × 53·06 × 63,360 ÷ 10,000,000) in., or 6·270 in.; and angle θ is (6·270 ÷ 29·872) radians, or (6·270 ÷ 29·872 × 57·3) degrees, i.e. 12° 01′. (Substantially the same would have been got from 18° 39′ × sin 40°, see p. 70.)

Referring to the figure, we have

$$x = \text{AO} - \text{AM} = r_0 - r\cos\theta.$$
$$y = \text{MD} = r\sin\theta.$$

$$\left.\begin{array}{lll} \text{L}\cos 12°\ 01' & \ldots & 9{\cdot}990\ 38 \\ \text{Log}\ r & \ldots & 1{\cdot}372\ 60 \end{array}\right\} \text{sum} = 1{\cdot}362\ 98 = \log \text{AM}.$$
$$\left.\begin{array}{lll} \text{Log}\ r & \ldots & 1{\cdot}372\ 60 \\ \text{L}\sin 12°\ 01' & \ldots & 9{\cdot}318\ 47 \end{array}\right\} \text{sum} = 0{\cdot}691\ 07 = \log y.$$

Hence, AM	... 23·066 in.		
AO	... 29·872 ,,		
x or OM	6·81 ,,	y,	4·91 in.

These are the distances required. They are called the rectangular co-ordinates of Danzig for the map (cp. pp. 94, 117). The origin of these co-ordinates is O, and the axes are the central meridian and the tangent to the standard parallel through the point where it is cut by the central meridian. As a rule, the main points on maps are plotted by means of such co-ordinates, which are computed for the intersections of the meridians and parallels to be shown on the graticule, as well as for other guiding points. These co-ordinates are called "northings" and "eastings" respectively, though, as in this case, they are not as a rule measured along either meridian or parallel. The x co-ordinates of points to the south, and y co-ordinates of points

to the west of the origin have the negative sign attached. Thus, in the question, one co-ordinate of Londonderry and both co-ordinates of Lisbon will be negative.

The co-ordinates computed may be checked approximately on any atlas map on a conical or on Bonne's projection. If the scale of the map be, for example, 1:25,000,000, it will be necessary to divide them first by $2\frac{1}{2}$.

17. Calculate the points in which the great circle passing through Cape Town (33° 56′ S., 18° 29′ E.) and New Orleans (30° 00′ N., 90° 00′ W.) cuts the meridians of 0°, 10°, 20°, . . . 180° E. and W., and plot the circle by rectangular co-ordinates on the maps of questions 11, 12. Check the work as far as possible by means of the cardboard ring.

CHAPTER IV

As in Chapter II the best type of exercise on this chapter is the actual survey on the ground of a definite area. Triangulation may be carried out by means of the instruments mentioned there. Failing anything better, the student can easily improvise simple plane-table and theodolite. With these he can make his survey, and if he does not get results of high accuracy, he can at least practise the methods of field-work and computation, discuss his results, and decide on their accuracy. This will ensure his grasp of the problems, and fit him to use the more refined instruments with intelligence when he has access to them and has learned how to handle them.

1. The following are the averages of the angles read at certain stations by means of a 3-in. theodolite:

At Station A.—	Deg.	Min.	Sec.	At Station B.—	Deg.	Min.	Sec.
Station D., R.O.	00	00	00	Station A., R.O.	00	00	00
,, C.,	44	28	50	,, D.,	44	20	50
,, B.,	98	09	10	,, C.,	79	45	30
At Station C.—				**At Station D.—**			
Station D., R.O.	00	00	00	Station C., R.O.	00	00	00
,, F.,	24	14	10	,, B.,	41	42	10
,, E.,	84	06	10	,, A.,	79	11	50
,, B.,	257	07	00	,, F.,	225	18	00
,, A.,	303	40	50	,, E.,	303	22	10
At Station E.—				**At Station F.—**			
Station C., R.O.	00	00	00	Station E., R.O.	00	00	00
,, D.,	39	16	10	,, C.,	41	09	00
,, F.,	78	59	10	,, D.,	62	13	10

The distance from C to D is 1525 ft., the bearing of D from C is 323° 16′, and the co-ordinates of C are 226, 2135 (in feet). Find at least two values for the co-ordinates of each of the other points, find how far each pair of values differs from their mean, and express this "divergence" in each case as a percentage of the co-ordinate.

2. Plot the points in question 1 on a sheet of paper about 10 in. square on the scale of 1:6000. On a sheet of tracing paper of about the same size plot the following angles, taken at the station K: A, R.O.; F, 261° 13′; D, 292° 34′; C, 322°. Fit the latter so that the proper rays pass through the points named on the former, prick through the position at K, and measure its co-ordinates (cp. the station pointer, p. 164).

3. Work out the co-ordinates of the points in the following traverse:

At A; B, R.O., sun at transit read (in azimuth) 67° 36′. Distance to B, measured up slope of 5°, 1594 ft.

At B; A, R.O.; angle to C, 132° 14′. Distance to C, up slope of 6° 30′, 2176 ft.

At C; B, R.O., angle to D, 75° 38′. Distance, down slope of 7°, 2075 ft.

At D; C, R.O., angle to E, 80° 45′. Slope 3° down, distance 2304 ft.

At E; D, R.O., angle to A, 212° 53′. Ground level, distance 617 ft.

At A; E, R.O., angle to B, 38° 30′.

Take A as origin of co-ordinates, and adjust traverse by dividing the closing error equally among the legs.

4. The following angles to P were read at A, B, C, D respectively in last question, the R.O. being as above: 7° 42′; 81° 45′; 22° 57′; 54° 02′. Obtain a check on the work of the traverse by computing as many independent values as possible for the co-ordinates of P. Find the effect on these co-ordinates of adjusting the traverse.

5. Plot the following points from their co-ordinates (in feet) on the scale of 1:15,000.

	x.	y.		x.	y.		x.	y.
K.	3249;	1958.	A.	2973;	5896.	B.	− 2024;	2190.
			C.	3071;	− 755.	D.	7086;	6949.

Calculate the bearings of the other points from K, and the angles which would be read to them from K, A being R.O.; and check these by measuring with the protractor the corresponding angles on the plan.

This calculation is merely the reversal of that employed on p. 116 for finding co-ordinates. Take, for example, the bearing of KD. Through D draw DM in the north and south direction, KM at right angles to it, that is, in the east and west direction. If KN is the north direction at K, the bearing θ of D from K is the angle NKD, which is equal to the angle KDM; and tan KDM = KM/MD. But KM is the amount D is east of K, that is, it is the difference between their y co-ordinates; and similarly MD is the difference between their x co-ordinates. Thus:

Co-ordinates of D,		7086 (x),		6949 (y).
Co-ordinates of K,		3249		1958
Difference,	dx,	3837	dy,	4991

log dy, 3·698 19
log dx, 3·583 99

Difference, L tan θ, 10·114 20 $\theta = 52° 27'$ to the nearest minute.

If d is the distance from K to D (KD in the figure), then

$$d = y/\sin\theta = x/\cos\theta.$$

Hence log dy,	3·698 19		log dx,	3·583 99
L sin θ,	9·899 18		L cos θ,	9·784 94
Difference,	3·799 01	= log d =		3·799 05

This provides a check on most of the arithmetic if worked out in duplicate as above. The difference between the two values of log d would disappear in five-figure logarithms if one worked to seconds. Of course the ratios only indicate angles up to 90°, while bearings run up to 360°. Hence it is necessary to draw a rough diagram for every case in order to see whether the bearing is between 0° and 90°, between 90° and 180°, between 180° and 270°, or between 270° and 360°. Thus B lies to the south and a little to the east of K (from the co-ordinates), hence the angle found by calculation must be subtracted from 180°; for it is always an angle measured from the meridian if the above mode of calculation is rigidly followed.

The method assumes that the meridians at all the points can,

for practical purposes, be taken as parallel; that is, the points must never be very far apart (see p. 11).

6. From the co-ordinates of K, in question 2, as measured, calculate the bearings from that point to A, C, D, F, and check them with the angles given. Account for any differences, and, if you can amend the measured co-ordinates, test the new values in the same way.

7. Obtain a quarter sheet of the O.S. 6-in. map of a rural district in your neighbourhood. With the aid of the contour lines engraved on it, and of the bench marks and other levels, sketch in contours at 25-ft. intervals. Take the map into the field and compare the actual features with your *interpolated* contours.

8. Make a sketch map with contours and isobaths to illustrate (*a*) a fiord coast-line backed by a table-land of a general height of 2000 ft.; (*b*) a low sandy shore with undulating lowland behind. Compare your sketches with colour-layered maps of Scandinavia or Scotland and the Baltic coast.

9. Draw a contoured sketch to show country crossed by two parallel scarps, with coast-line transverse to the line of the scarps, and compare your sketch with a colour-layered map of south-east England.

10. A point Q lies at an altitude of 1000 ft. on a ridge joining two peaks B and C, and due east of and 1860 yd. from P, which is a point at the same level in a col between two peaks, C and A. *Bearings* were taken more or less roughly as follows:

At P, to A,	0°.	At Q, to A,	319°.	At A, to B,	95°.
B,	59°.	B,	34°.	C,	165°.
C,	141°.	C,	224°.		

The following angles of elevation were also taken:

At P, to A,	7° 00′.	At Q, to A,	5° 30′.
B,	5° 00′.	B,	8° 15′.
C,	14° 40′.	C,	13° 30′.

Half-way between A and B is a circular lake, a quarter of a mile in diameter, the surface of which lies 517 ft. above sea-level. Make a contoured sketch of the area on the scale of 1:20,000.

CHAPTER V

Field-work in map-reading is as important as field-work in survey. The student is advised to obtain O.S. maps of the

district in which he lives, and to make excursions to compare them with the features they represent. A map may be used for two purposes: in the field in strange country as a guide; and in the office to indicate the appearance in the field of a piece of country, and the relations of its features. For both of these map-reading in the field is the only adequate preparation.

1. If a side of one square of the grid on the Salisbury Plain map (p. 156) represented a distance of 7 miles, what would be the R.F. for the map?

2. You are in the field with a map, and wish to use it, but you do not know the country sufficiently well to orient the map from the features shown. How would you proceed (*a*) if you had a pocket magnetic compass; (*b*) if you had no compass, but there was bright sunshine?

3. Three points shown on a map are easily identified on the ground by a traveller who wishes to "spot" where he is, and to orient his map. How would he go about it? (Cp. resection, p. 122: the map may be laid on the ground or held flat in the hand, and a pencil or a scale used as an improvised alidade.)

4. Mark these points on the Salisbury map, A, 51° 19′ 22″ N., 1° 59′ 10″ W., B, 51° 09′ 50″ N., 1° 42′ 40″ W., and draw a section along the line joining them.

5. Would anyone near the Roman Way, in B7 in the above map, be able to see any of the points in the valley to the north in order to locate himself by the method of question 3? The section of question 4 will suggest the answer.

6. The *Observatory*, C7, in the Salisbury map is a tower 45 ft. high. Will it be visible (*a*) from a point 800 yd. E.N.E. by compass from the well in C7; (*b*) from Little Farm in B6? Draw sections between the Observatory and each of these points to confirm your opinion.

7. A person benighted on Salisbury Plain knows that he passed Beggar's Knoll, east of Westbury (C2) at 4.15 p.m., and walked at a fair rate east by south. It is now 6.35 p.m. Where is he likely to be, and what would be his best course towards an inn in which to spend the night?

8. On the map of question 10, p. 300, show a road running by the lake and past the point P, such that the steepest slope on it does not exceed 1 in 20.

9. Estimate the greatest, least, and average gradients on the mineral line leaving the railway at Drishaig, in the Oban map (F9).

10. It is proposed, in connection with a small hydro-electric scheme, to raise by means of a dam the level of Loch Nant (Oban map, G-H 5) to 770 ft. Mark (*a*) the places where it seems to you the dam (or dams) would be best constructed; (*b*) the area covered by the reservoir when full; (*c*) where water-turbines might be situated so that there should be a head of 280 ft. of water when the reservoir was at its minimum level of 700 ft.; (*d*) the course of a construction railway from Taynuilt Pier to the main dam, so built that gradients do not exceed 1 in 40.

11. Having regard to its scale, of what use would the map prepared in last question be in relation to the scheme?

12. From the orographical map in your atlas draw a map to show the British Isles as they would appear if the land were to sink uniformly by 600 ft. Write an account of the coasts which would result, and compare them with the present British coasts.

13. Construct a map to show north-western Europe at the time when the raised beach 100 ft. above the present sea-level was being formed.

14. Divide the area shown on the Oban map into the chief river-basins.

15. Draw a map of Great Britain showing the main watershed and the chief secondary watersheds. Insert also the main railways, and indicate the gaps by which they negotiate the crossing from one river-basin to another.

16. Draw a map to show the importance of the gaps in the Downs and the English escarpments. Write notes on the courses of the main railways through the scarps.

The student should take every opportunity of studying maps of every different type and scale as it arises. He may apply many of the above questions to other topographic maps, and devise for himself many more on the same plan.

Answer—1. 1:221,760.

CHAPTER VII

The daily weather charts of the Meteorological Office are displayed in some public places and are reproduced each morning by certain newspapers. These should form the study of students for whom they are available.

1. On a blank map of the world put in from your atlas the mean annual isotherms of 40° F. in the northern, and 70° F. in the southern hemisphere. Indicate the ocean currents and pre-

vailing winds along the course of these isotherms, and write a note to account for their main vagaries.

2. On the isotherm charts in your atlas for the world in January, July, and the year, sketch the course of the heat equator. Compare its position and form in the three cases.

3. Estimate the mean annual temperature on the heat equator every 20° east and west of Greenwich.

4. From the temperature maps in your atlas compile a table showing the mean temperatures for January, July, and the year, and the mean temperature range (difference between January and July means) for the following places: London, Fort William, Valencia Island, New York, Winnipeg, San Francisco, Timbuktu, Lyons, Berlin, Madrid, Moscow, Petrograd, Lhasa, Irkutsk, Canton, Pekin, Vladivostock. Examine your table in relation to latitude, distance from sea, prevailing winds, and nearest ocean currents, and embody your conclusions in a note.

5. It has been calculated that the mean temperatures (Fahrenheit) for different latitudes on the earth are according to the following table:

	Latitude in Degrees.																
	North.									South.							
	90	80	70	60	50	40	30	20	10	0	10	20	30	40	50	60
Annual	− 4	2	13	30	42	57	68	77	80	78	77	73	64	53	42	30
January	− 36	− 28	− 15	4	20	40	58	72	78	79	79	77	71	59	47	35
July	34	36	44	57	64	75	81	82	80	77	75	68	58	48	37	25

Determine where the temperatures are higher than the average and where lower, and shade the warm regions red, the cool blue, on a map of the world. Compare the map with the corresponding isobar charts in your atlas, and write down your conclusions. (The difference between the mean temperature for any place and the mean temperature for its latitude is called its *temperature anomaly.*)

6. On blank maps of India insert the isobars for the months of July and January, and put arrows to indicate the winds which should result. Using ink or pencil of another colour, insert the actual winds from your atlas, and account for the main discrepancies. (Note the lofty continuous barrier of the Himalaya in the way of the surface winds, the elevated block of the Deccan, and the low-lying through-valley followed by the lower Indus and Ganges systems between.)

7. Compare, chiefly in respect of prevailing winds, temperature, and rainfall, the climates of Vancouver Island, Newfoundland, and Ireland. Account for the differences.

8. Make a sketch map or maps to show the main elements of climate in West Africa and America in the neighbourhood of lat. 20° S. Show from the maps how ocean currents *in conjunction with prevailing winds* determine very largely the temperature and rainfall of adjacent lands.

9. A large depression centred off the south-west of Ireland is moving in a north-easterly direction. Show the depression in an isobar chart, isobars being drawn for every 5 mb. (1000 millibars = 29·53 in. of mercury, 1050 mb. = 31 in.). Indicate the general weather changes which will take place during the ensuing few days at Southampton and Stornoway.

The strength of the wind is indicated by the Meteorological Office and other scientific bodies at home and abroad by a number on the scale devised by Admiral Beaufort in 1805. This scale is given below for reference and for use in some of the accompanying exercises in the form at present adopted. The velocities in miles per hour are those given by Napier Shaw, and are, for several reasons, rather lower than those given in American and other tables.

Beaufort Scale of Wind Force

(Generally after Sir Napier Shaw)

Number on Beaufort Scale.	Name of Wind.	Effects by which strength of wind may be judged.	Velocity of air in miles per hour.
0	Calm	Smoke rises vertically. No perceptible movement of objects.	0–1
1	Light air ...	Smoke drifted by wind, but wind-vanes not turned. Boats[1] have just steerage way.	2
2	Light breeze ...	Wind felt on face; leaves rustle; wind-vanes turned. Sails fill, and boats move at 1–2 knots.	5

[1] Ordinary sailing trawlers or herring-boats in average order referred to. Small boats and larger vessels may behave differently.

Number on Beaufort Scale.	Name of Wind.	Effects by which strength of wind may be judged.	Velocity of air in miles per hour.
3	Gentle breeze	Leaves and twigs in constant motion; light flags extended. Boats begin to heel; and sail 3–4 knots.	10
4	Moderate breeze	Dust and loose paper raised; small branches of trees moved. Good sailing breeze; boats carry full sail and heel well over.	15
5	Fresh breeze ...	Small trees in leaf sway; wavelets appear on inland water. Boats shorten sail.	21
6	Strong breeze ...	Large branches sway; wind whistles in telegraph wires; umbrellas hard to hold. Boats carry mainsail double reefed.	27
7	High wind ...	Whole trees sway; wind begins to impede walking. Boats remain in port, or, if at sea, lie to.	35
8	Gale	Twigs broken off trees: walking against wind very difficult. All boats make for harbour.	42
9	Strong gale ...	Chimney pots and slates removed; slight damage to structures—hoardings, &c.	50
10	Whole gale ...	Trees uprooted. Considerable damage to structures. Winds of this strength uncommon inland.	59
11	Storm	Widespread damage. Such winds very rare.	68
12	Hurricane ...	... ...	above 75

10. Mark the centres, or points of lowest pressure, of the cyclone, in figs. 107, 108, pp. 212–3, and estimate the rate of travel of the disturbance. Draw a line to show approximately the trough of the depression (line through the centre at right angles to the path of travel). Describe the changes in wind and temperature which take place at a point as the trough of the cyclone travels across it.

11. When the wind at a place changes steadily in a clockwise direction (e.g. from east through south-east and south to south-west and west, or, as is often said in the northern hemisphere, "with the sun"), it is said to *veer*. A steady change in the opposite direction is called *backing*.

A cyclone is passing in the neighbourhood of a place in the northern hemisphere. Where is the centre of the cyclone with relation to the place if the wind is (*a*) veering, (*b*) backing? What will be the succession of weather changes in either case, and what type of weather do veering and backing winds respectively presage?

12. A ship is sailing westward in lat. 28° N., long. 75° W., when rapid fall of the barometer indicates the approach of a tornado.[1] The wind is a little west of south, but steadily shifts more to the west. How must course be altered in order to escape the violence of the centre of the storm? If the wind were, and remained, south, where would the centre or "eye" of the storm lie?

13. Account for the fact that in fig. 111, p. 216, rain is shown to fall chiefly along the trough of the depression. (To the west of the trough a cold air-current flows down from the north, and meets on the trough a warm current from the south. How will the air of the two currents behave where they meet?)

14. In fig. 112, p. 217, strong winds are indicated at Lerwick and Stornoway, weak ones at London and Yarmouth. Explain this.

Measure as nearly as possible the perpendicular distance between consecutive isobars on either side of these places, and calculate the barometric gradient at each in millibars per degree of latitude. Divide the velocity at each place by the gradient, tabulate the results, and state any conclusions you reach.

15. Measure the angles between the wind direction and the tangent to the isobar at Stornoway, Lerwick, Yarmouth, Aberdeen, Holyhead, Biarritz, and Lisbon, in fig. 112, p. 217, compare them with the wind velocities in miles per hour (see table of Beaufort Scale above), and state any conclusions you may reach. Note and explain if possible any exceptions to be found in the weather charts in this book.

16. Write notes on the relation of wind velocity and direction, and atmospheric pressure at Malin Head and Ushant in fig. 107,

[1] A tornado is a cyclone of small extent but great violence characteristic of parts of the warm seas off American, Indian, and other coasts.

at Channel Islands, Biarritz, Stornoway, and Scaw in fig. 108, and at Ushant, Christiansund in fig. 112. Try to explain any anomalies.

Answers—

1. The bends of isotherms are due to the different rates of heating of land and sea, and to the effect of sea winds blowing inland from warm or cold ocean currents. They take place where land and sea meet.
4. The temperature range is high in the interior of continents and in high latitudes, low on or near the coast and in low latitudes. Temperature is high for the latitude at places on the lee side of warm ocean currents, cp. Valencia Island and Winnipeg.
5. Permanent cyclonic areas correspond with positive temperature anomalies—places which are warm for their latitude—and anticyclonic areas with places of negative temperature anomaly.
9. At Stornoway the wind will change from south-east to east and north-east. There may be rain at first, but the sky will clear and the weather become dry and colder. At Southampton there will be south wind with rain and cloud, which will continue for a time. The wind will shift to south-west, west, and north-west. Temperature will remain high, but will fall with clearing skies as the wind becomes more northerly.
10. As at places above (answer to question 9) according as the point lies to the north or south of the centre.
11. (*a*) To the north; (*b*) to the south of the place. Changes as in questions 9 and 10.
12. Alter course more to the south. Steady south wind shows that the centre is dead ahead.
14. Steeper gradients as a rule mean stronger winds.
15. The higher the wind the more nearly along the isobar it blows. Exceptions may be due, among other things, to the uncertainty of the whole course of the isobars (cp. pp. 186, 217), and to the existence of secondary disturbances missed by isobars drawn at 5 mb. interval.

CHAPTERS VI, IX

1. A ship's head bears 124° by compass. Observation shows that the sun at noon is 29° to starboard of her head. The ship being in the northern hemisphere, find the error of her compass.

2. Express the following bearings in degrees, reckoned up to 360° from N.: S.E., N.N.W., N. 50° E., S. 15° W., N. 61° W., S.W. by W., W. by S.

3. Convert the following magnetic bearings into true, the variations being in each case given in brackets: N. 69° W. (14° E.), S.E. (24° E.), N. by E. (17° W.), W. by N. (17° E.).

4. The approximate positions of Albany, Western Australia, and Bahia Blanca, Argentine, are 35° S., 118° E., and 40° S., 62° W., respectively. What is the great circle course between them, and is it practicable?

5. Explain the following entries on a chart: H.W.F. & C., XI, Lt. Grp. Occ. ev. 30 sec.; $\frac{49}{\text{w.s.}}$; $\frac{198}{\text{brk.sh.}}$; $\frac{206}{\text{st.}}$; $\frac{\cdot}{100}$.

6. A survey ship lands a party who set up an observing station at A on the north-east corner of a bay in north latitude. She then takes up a position at X, where she makes observations of certain angles, and angles are taken to her from the shore. From X she steams S.S.E. (true), seven knots, for thirty-three minutes and anchors at Y, where angles are again taken. From Y twenty-two minutes at seven knots due N. take her to a point where the north-west corner of the bay bears N.N.E., distant 300 yd. Meanwhile the shore party set up a station at B in the south-east corner of the bay and another at C at the south entrance. They measure AB (2992 yd.), and angles at B and C. They observe that at B the shore of the bay is on the one side parallel to AB, and on the other trends N.W. by N. From C they find that the general trend of the coast to the north of the bay is N.N.W., to the south, S.W., and that the general direction of the south side of the bay there is E. by N. The angles observed are:

	Degrees.	Minutes.
At A.—Sun at noon, to Right of B	17	06
C, ,, ,, B	45	24
Ship at Y, ,, ,, B	33	48
Ship at X, ,, ,, C	72	11
Hill top R, to Left of B	27	54
Hill top P, ,, ,, R	117	15

			Degrees.	Minutes.
At X.—P,	to Left of A	... ...	40	11
Hill top Q,	,, ,, A	... ...	15	21
R,	to Right of A	... ...	21	04
B,	,, ,, A	... ...	21	07
C,	,, ,, A	... ...	31	29
At B.—C,	to Left of A	... ...	66	24
X,	,, ,, A	... ...	41	19
Y,	,, ,, C	... ...	56	01
P,	to Right of A	... ...	22	20
At C.—X,	to Left of A	... ...	76	19
Q,	to Right of A	... ...	29	55
B,	,, ,, A	... ...	68	11
Y,	,, ,, B	... ...	90	13
At Y.—Q,	,, ,, A	... ...	27	37
R,	,, ,, A	... ...	73	18
B,	,, ,, A	... ...	23	47
C,	to Left of A	... ...	10	00

Plot these angles by the method of chords on the scale of 2 in. to a nautical mile, and sketch in the features on the chart as far as the data go.

(Note, all the plotting must be done from the measured base; the distance between X and Y may be got roughly by dead reckoning, and the position of Y fixed thereby with reference to that of X; this must be regarded as providing a check, but a rough one only, on the work. The number of angles is sufficient to provide ample accurate checks on observation and plotting.)

7. A ship arrives off the bay in the chart of question 6, and proceeds to test her compasses. Sextant angles are read as follows: between P and Q, 26° 01′; between Q and south-west head of bay (C), 19° 04′; between C and R, 20° 25′. Compass bearings from the ship are: to P, N. 59° E.; to Q, N. 87° E.; to C, S. 77° E.; to R, S. 57° E. Fix the position of the ship by means of the station pointer (or use tracing paper as in question 2, p. 296), and determine the error of the compass in each of these directions.

8. Show by a "compass" on the chart of question 6 the magnetic variation derived from the following observations, and find the deviation of the ship's compass:

Compass bearings at:

A.—B, due S.	B.—A, due N.
C, S. 45° 20′ W.	Q, N. 63° 30′. E.

From ship at X, to P, N. 71° E., to Q, S. 80° E.

From ship at Y, to P, N. 32° E., to Q, N. 59° E.

Find also the deviation of the compasses of the ship in ques
tion 7.

9. Soundings made from a boat keeping B and R in line ar
to be added to the chart of question 6. Plot them from th
following table:

Magnetic bearing to A.		Depth in fathoms.		Nature of bottom.
N. 6° E.	...	2	...	Mud.
17	...	$3\frac{1}{2}$	...	Mud.
28	...	6	...	Fine sand.
38	...	7	...	Coarse sand.
47	...	$7\frac{1}{2}$	...	White sand and shells.
56	...	$6\frac{1}{2}$	...	Broken shells and gravel.
67	...	5	...	White sand.
76	...	$3\frac{1}{2}$	...	White sand.
83	...	4	...	Rock.
89	...	6	...	Rock.

10. Plot on a Mercator map by the method of p. 292, question 1
the great circle course from Cape Town to Hobart. Compare
with that shown in your atlas, and explain the differenc
(Cape Town is in 33° 56′ S., 18° 29′ E., and Hobart in 42° 53′ S
147° 21′ E.; but in order to clear the Cape of Good Hope and th
south-east cape of Tasmania, calculate the circle from 34° 20′ S
18° 00′ W. and 44° 00′ S. and 147° 00′ E. Check all through b
means of the card ring.)

11. Vessels sailing in the winter from Southampton to Ne
York on reaching 49° 30′ N., 7° 00′ W. set a great circle cours
for a point in 41° N., 47° W., whence they sail along the parall
to 74° W. Assuming the great circle is followed by sailing sho
rhumbs, find the length of the passage from 49° 30′ N., 7° 00′ W
Check as far as possible by means of the card circle. (Calcula
the latitude in which the great circle cuts the parallels of 12°, 17
22°, . . . 47° W., then calculate the lengths of the short rhum
as on p. 252.)

12. Calculate the rhumb line distances between Newcastle-o
Tyne and Bergen, and between Leith and Hamburg. (Deci
from your atlas the approximate position of the points betwe
which there is straight open-sea sailing, and calculate the di
tances between these. Measure as near as possible from th
maps the additional distance to or from port.)

13. Follow the main routes from London to Port Said used b
ships sailing to the Orient, as indicated in advertisements and

your atlas, and account for the calls made. Do the same for the passages from Aden to Calcutta, from London by the Cape to Rangoon, and from Panama to Yokohama.

14. A tramp steamer in pre-bellum days specialized in carrying wheat to the United Kingdom. Assuming she was employed constantly throughout the year, to what ports abroad would she sail at different seasons?

15. A ship in 48° 12′ N., 15° 20′ W., ran 1005 sea miles west (true). What was her final position?

16. A ship sailing east made good 500 miles departure, and altered her longitude by 16° 40′. What was her latitude?

17. A vessel in 49° 46′ S., 34° 15′ W., sets a course N.N.W. by compass, and keeps it throughout a watch (four hours), doing an average of $15\frac{3}{10}$ knots. Wind is E.N.E., she makes leeway of 12°, deviation on the course is 7° E., variation 13° W. What is her dead reckoning position at the end of the watch?

Answers.—

1. 27° E.
2. 135°, 337° 30′, 50°, 195°, 299°, 236° 15′, 258° 45′.
3. N. 55° W. (305°); S. 69° E. (159°, nearly S.S.E.); N. 5° 45′ W.; N. 61° 45′ W. (298° 15′).
4. Along the meridian by the South Pole.
7. 19°, 21°, 18°, 18°, all W.
8. Variation 17° W.; deviation, 2° E., 2° E., 6° E., 2° E. on courses N. 32° E., N. 59° E., N. 71° E., S. 80° E. (by compass), respectively.
11. Southampton to 49° 30′ N., 7° 00′ W., 225 sea miles; great circle, 1546, parallel, 1223, total, 2994 miles.
12. 410, 415 miles.
15. 48° 12′ N., 40° 25′ W.
16. 60° N. or S.
17. 48° 59′ S., 35° 06′ W.

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